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COMMON PROPERTY AS AN INSTITUTIONAL RESPONSE TO ENVIRONMENTAL VARIABILITY

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> "A whole village may depend on rainfall conditions within a single square kilometre. Under such circumstances, spatial variations in rainfall for individual days are perhaps more important than is generally realized, except by the peasant farmer. Since a large proportion of the rain occurs in a few days, whether or not a single heavy storm 'hits' an individual small area, particularly at the start of the rainy season or at certain short, critical periods in a crop life cycle, could mean the difference between success and failure."
>
> J. Jackson (1978, p.284)

Introduction

The debate surrounding the efficacy of common property regimes has shown that a continuum of property regimes exists. Also, an ebb and flow between regimes occurs as societies change. Open access, state, common and private property represent the major categories along this property continuum. Each can be differentiated by decision unit, benefit incidence and regulations. Open access is a free-for-all where benefits accrue to the agent that can exploit the resource first. No institutional rules limit the agent's behavior. Government agencies manage state property in such a manner that benefits accrue to agents with permits authorizing access and regulating use of the resource. Common property provides for co-equal rights to a bounded resource where group-established rules govern resource use. Finally, private property empowers owners to experience the private costs and benefits from their actions subject to broad societal guidelines or constraints.

Economists have stressed in their models the management of established rules to insure economically viable common property regimes (Wade 1987; Stevenson 1991). Cooperative arrangements in these models, where rules exist to discourage shirking by individuals in the group, can produce a sustainable economic environment. However, these institutional arrangements alone may not give a complete picture of the incentives confronting the individual in a common property regime.

We argue that environmental conditions can play an equally important role in the determination of optimal property regimes. Environmental uncertainty in the form of extreme rainfall variability across time and space produces an incentive to develop cooperative rules which insure access to widely dispersed fields or grazing areas. We therefore reformulate Bromley's (1989, p. 15) equation which relates property rights to economic yield to read,

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$$Property\ Regime = f\left(\mu_p, \sigma_p^2\right) \quad (1)$$

where μ_p and σ_p^2 are the mean and variance of physical yields respectively.[1] These first two moments of the probability distribution for yields can be directly related to economic welfare through an expected profit equation. Higher order moments also could be included. We hypothesize that environmental variability is particularly relevant on land at the extensive margin, i.e., land in the semi-arid and arid-regions of the world where low mean productivity and high yield variability predominate (Bromley and Cernea 1989). Other authors have recognized the importance of the second moment in this functional relationship but have failed to verify variability in rainfall with meteorological evidence (Sandford 1983; Runge 1986).

The focus in this paper is on environmental variability across space. For subsistence ranchers or farmers with high discount rates, the intertemporal aspects of variability are probably less important than the area distribution of rain within one growing season. We relate the meteorological literature on rainfall variability, emphasizing correlation-distance relationships, to two risk-spreading models found in the economics literature. We postulate that common property can be a rational response to environmental variability.[2] These understandings are applied to grazing systems in Kenya and Mexico where privatization efforts have been implemented or are being explored.

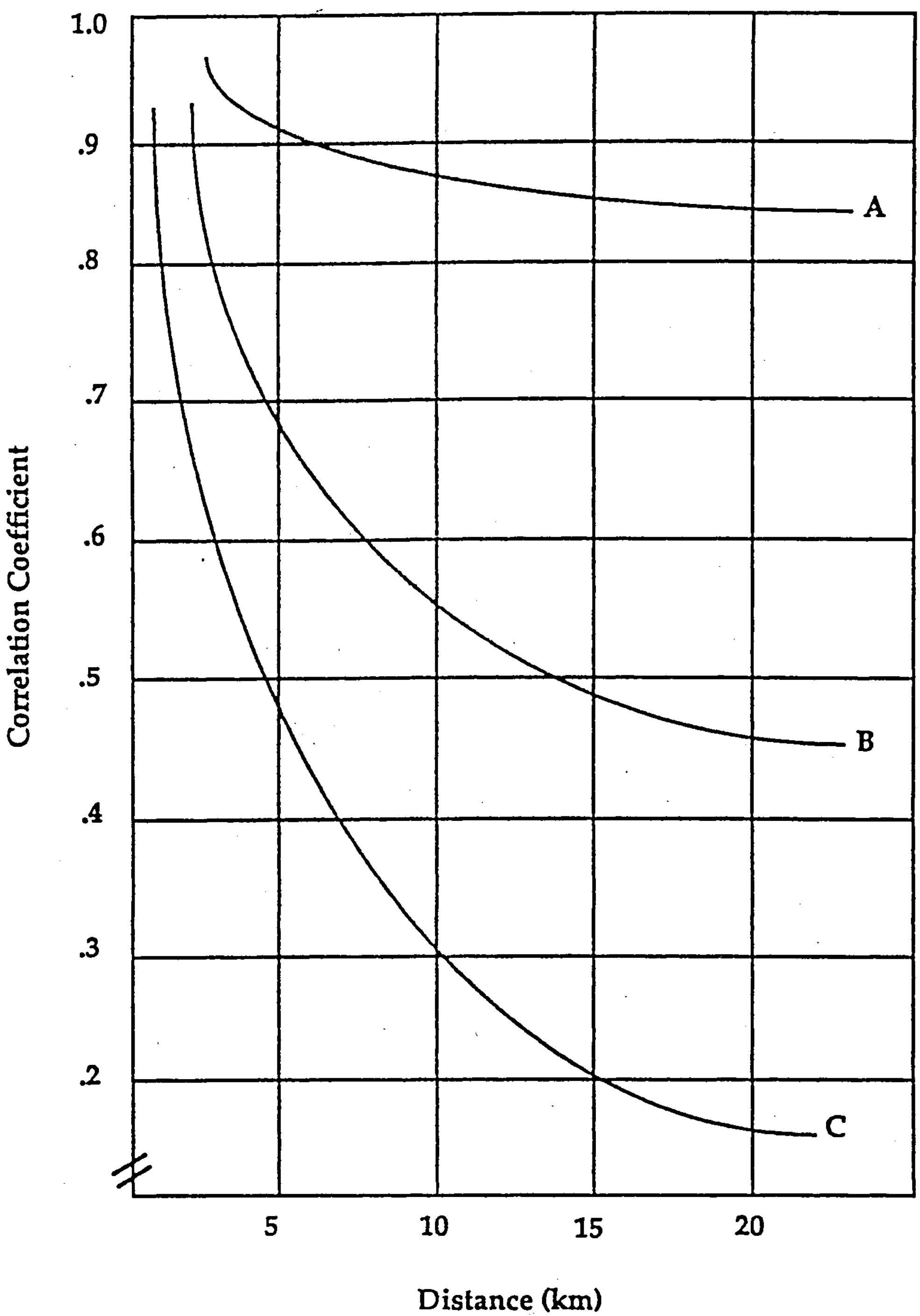
Environmental Variability Over Space

Measures of average annual rainfall are often used to characterize a specific geographic region. Although these aggregate statistics provide useful information for interregional analysis, they do not capture the nature of the variability within a region. Intraregional variability has been well understood by herders and farmers for millennia as an important source of risk. Yet the potential importance of spatial variability in rainfall for land use decisions has remained in the background of property regime analysis.

Figure 1 presents three representative correlation-distance functions for rainfall. Empirically, these relationships are estimated using rainfall measurements from a network of rain gauges over a watershed. Pairwise correlations are tabulated for hourly, daily or monthly rainfall using $r_{ij} = r(d_{ij})$ where r_{ij} is the correlation coefficient between stations i and j and d_{ij} is the distance between the reporting stations or rain gauges. Curves, similar to A, B, and C in Figure 1, then are fitted through scatterplots of the individual correlation coefficients.

Three factors affect the slope and location of these spatial correlation relationships. First, latitude is a determinant of the relative mix between convective and frontal storms. Regions in higher latitudes have relatively more widespread frontal storms throughout the year which produce a correlation-distance function resembling A. Lower latitude areas where convective storms, with high rain intensities for short periods of time, are reflected in functions B and C. A second determining factor is topography. Orographic effects from mountain ranges and coastal influences produce spatial variability.[3] For example, location near mountains sharply

Figure 1: Representative Correlation-Distance Relationships for Rainfall.



rising from a valley floor may produce a rainfall pattern dissimilar to the one in the central valley only several kilometers away. Finally, as the interval of observation increases, e.g., from daily to monthly intervals, the slope of the correlation-distance functions "flattens." For example, C could represent the hourly rainfall relationships while B and A might reflect the daily and monthly data respectively.

Empirical measurements of rainfall dispersal from various latitudes demonstrate the effects of convective storms, orographic effects and interval of observation on correlation-distance relationships.

Saskatchewan, Canada (Lat. 50° N)

McConkey, Nicholaichuk, and Cutforth (1990) used data over a 34-year period from a combination of 11 rain gauges spaced 800-4,400 m apart. They evaluated spatial variability over this small area by storm and by month. The estimated spatial distribution function related to storms demonstrated a slope similar to the monthly function, but with a lower intercept on the y-axis. Over a distance of 4,000 m the monthly spatial correlation values declined from 0.99 to 0.95. An extrapolation to 15 km produces a coefficient of 0.85, a gradual rate of decay over a moderate distance. These results are compatible with function A in Figure 1 and reflect precipitation relationships for relatively higher latitude regions.[4]

Illinois, U.S.A. (Lat. 40° N)

Insights into the spatial distribution of rainfall in the midwestern U.S. were obtained by Huff (1960). Using a network of 50 recording rain gauges over an area of 161 kms, a 29-storm sample of 1-minute rainfall rates was obtained during the warm seasons of 1952 and 1953. Spatial correlation decayed very rapidly over instantaneous 1-minute rates. Within three kilometers correlation declined from 1.0 to 0.6. Over a distance of 16 km spatial correlations fell to 0. These results resemble relationship C in Figure 1. However, when total storm rainfall was correlated with the distance between rain gauges a totally different picture emerged. In this aggregated case the data resembled relationship A. Spatial correlation declined very slowly to a value of 0.8 after 16 kilometers.

Israel (Lat. 32° N)

Sharon (1972, 1979) has reported on the localness of rainfall in two regions of Israel: an area near the Gulf of Aqaba and the Jordan Valley. In the arid southern region, daily rainfall data were obtained from five reporting stations within 25 km of one another. Data were gathered over a variable number of years (i.e., 2-9) depending on the station. Rainfall was found to be highly variable with respect to time (i.e., year to year) and space. For several years, one station reported receiving nearly its average annual total (23 mm) over a four-day period while the other stations during the same period received very little rain (0-3 mm). In this arid environment, correlation-distance functions decayed rapidly. At 3 km a correlation coefficient of 0.9 was obtained while coefficients of 0.6, 0.5, and 0.25 were calculated at the 5, 10 and 15 km distances respectively. For daily data this relationship reflects function C in Figure 1.

In the study of the Jordan Valley daily rainfall data from 92 stations over seven winter seasons (1960/61-1966/67) were analyzed. Spatial correlation functions generally maintained their relative slopes but shifted towards the origin as the location of the reporting station moved southward. For example, the spatial correlation at 20 km was approximately 0.7 at Jericho but nearly 0.9 at Ghor Fara which is 50 km to the north. Sharon hypothesized that orographic effects contributed to greater precipitation uniformity in the northern area of the study region.

Southwestern U.S.A. (Lat. 32° N)

The Walnut Gulch Experimental Watershed utilizes a dense system of rain gauges (0.8 km radius per gauge) over an area of 176 km^2. Located on the northern edge of the Chihuahuan Desert, rainfall data from this station reflect general precipitation conditions in the southwestern United States and northern Mexico. Using 40 gauges for the period 1961-1972, Osborn, Lane, and Myers (1980) approximated a spatial correlation function for storms in the watershed. At approximately 2 km, correlation varied around a mean of 0.8 but fell rapidly to 0.6 and 0.2 at 5 and 10 km respectively. The authors failed to find any statistically significant orographic effect in the watershed within the 450 m elevation range. Significant localness in rainfall was attributed to the convective nature of the major rain producing storms during the monsoon-like season (July-September).

Tunisia (Lat. 35° N)

In this case, data were collected during 1982/83 from seven rain gauges over a 19.2 km^2 catchment area in a suburb of Tunis (Berndtsson and Niemczynowicz 1986). Spatial correlation relationships were developed for hourly, daily and monthly rainfall data. Hourly correlations between stations declined to less than 0 within 3 km; a correlation distance relationship much steeper than curve C in Figure 1. Daily and monthly correlation functions were less steeply sloped. These coefficients followed the now familiar pattern of decline from 1.0 to 0.6 over a distance of 6 km, thereby resembling relationship C.

Tanzania (Lat. 4° S)

Spatial patterns in rainfall in tropical Tanzania have been investigated by several researchers. Using an eight-year period, Sharon generated correlation coefficients related to distance for 14 rain gauges over a 30,000 km^2 area in northern Tanzania (Sharon 1974). The decay over relatively short distances (< 20 km) was dramatic, with correlation coefficients declining from 0.8 at 5 km to 0.1 at 20 km. Sharon states,

> "What may be unique to the tropical area is the fact that a correlation that low applies to daily rainfall *in general* (Sharon's emphasis), and not only to a certain portion of selected raindays, as in higher latitudes. This reflects the predominant role of small-scale convection in the region dealt with. Still, if data for appropriately selected days would have been used here, the resulting correlation coefficients would be even lower, i.e., significant negative values would certainly have resulted" (p. 213).

In a 56, 250 km^2 catchment area in central Tanzania, Jackson (1978) estimated spatial correlation coefficients for 25 stations. Over a 25-year study period average monthly correlations between stations declined rapidly within the first 20 km. Spatial correlations for most months declined at least 30 percentage points over this short distance. Average monthly correlations varied from 0.3 in April to 0.7 in October. Jackson concludes his article by stating that, "The degree of local differences in rainfall variability patterns could be an argument in favour of fragmentation of holdings . . ." (p. 285).

Jackson's general findings were supported later by the research in coastal Tanzania (Sumner 1983). Daily rainfall data were obtained from an extensive network of rain gauges in and around Dar Es Salaam. Spatial correlation values of less than 0.3 were realized within distances under 10 km. After 10 km the distance-decay relationship became relatively flat with correlation coefficient values ranging between 0.0 and 0.3.

In summary, the meteorological evidence indicates that rainfall variability over space is a fundamental characteristic of nature which normally is not captured in standard economic analysis of agriculture. Nor is this fundamental characteristic of nature recognized in public programs directed at the agricultural sector. The degree of rainfall variability is a function of latitude, storm patterns, and the topography of the region. Variability in rainfall across space may occur at critical flowering or growing periods in the crop or forage biological cycle. As a result, we should expect significant yield, and hence economic, variability across space as well.

Spatial Diversification

Successful agricultural production is largely determined by natural elements such as pests, rainfall, temperature (e.g., frost) and soil quality. The localness of these environmental conditions is understood by farmers and herders in diverse areas (Netting 1976; Guillet 1981). Just as investors diversify their financial portfolios to reduce risk and increase average returns, farmers and herders will attempt to diversify their yield portfolios over space to insure economic sustainability. As seen in the following two models of land at the extensive margin, farmers and herders who diversify geographically may be making reasonable, if not rational, decisions in response to environmental variability.

A Statistical Model

Aggregation issues surround the use of area or regional data to reflect economic reality at the firm level. In the U.S., county and state data often have been used in policy analysis in the agricultural sector. Although aggregate statistics may be the only available data, their use can seriously understate the level of variability experienced by individual farmers.

Nearly 30 years ago Eisgruber and Shuman (1963) developed a formal statistical relationship for aggregation bias. Assuming all farm-level variances are the same ($\sigma_1 = \sigma_2 = \ldots \sigma_n = \sigma$) for all n farms and that r, the correlation coefficient, represents an arithmetic mean of all cross-correlations, the aggregate variance is:

$$\sigma_A^2 = (\sigma^2 / p)\,[1+(p-1)r] \tag{2}$$

where p is the number of farms or plots. The aggregate variance is a declining function of p and as the correlation between farms declines, so does the degree of overall variability.

Spatial diversification to reduce environmental and economic variability would require an increase in the number of farms holding the average correlation-distance relationship constant. Correlation values approaching one reduce the incentive to diversify over space while lower correlation coefficients increase the difference between farm-level variability (σ^2) and the aggregate variability measure (σ_A^2). Therefore, there is more incentive to diversify geographically in the tropics of Tanzania or the deserts of Arizona and Mexico, than in the plains of Canada. As the reviewed meteorological literature has shown, correlation between farms can fall dramatically over a 5 km range in some areas of the world.

A Behavioral Model

Historical evidence from England during the Middle Ages provides additional insights on the value of spatial diversification (McCloskey 1975, 1976, 1989). McCloskey's painstaking research suggests crop yields varied markedly across plots as nearby as 5 km. Variations in yields were caused by changing soil quality over short distances as well as by other localized events, e.g., pests, disease, rain and hail. Scattering of land holdings offered peasants in the English commons a means to insure against vagaries in crop yield.

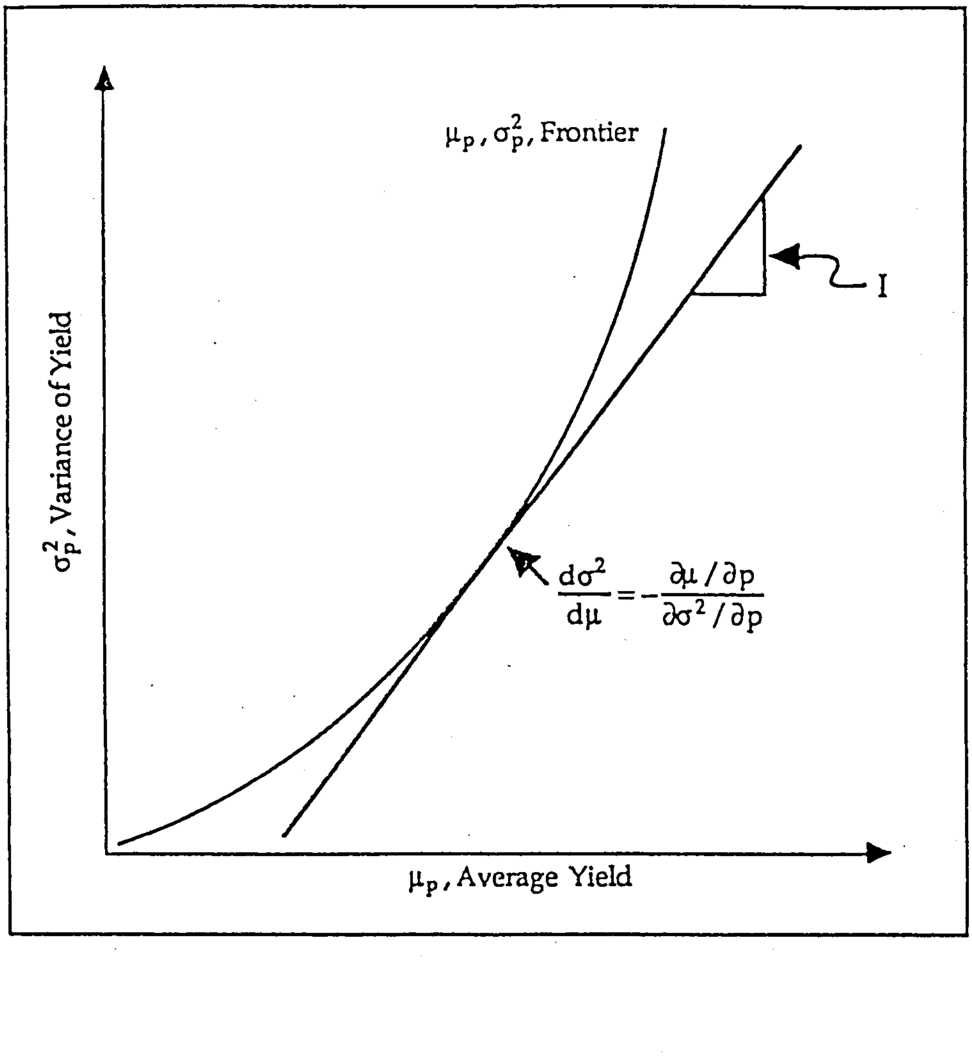
The behavioral model underlying McCloskey's arguments posits that farmers are concerned with both average yield and variation in yield. The potential trade-off between mean yield and the variance of yield which farmers may face is displayed in Figure 2.[5] The mean-variance frontier for yields indicates that higher mean yields can only be attained by incurring higher variance of yields. The rate at which a farmer is willing to sacrifice mean yield for a reduction in the variance of yield, I, can be considered as a measure of the farmer's aversion to risk. In the following analysis, the slope I $\left(-\frac{\partial\mu/\partial p}{\partial\sigma^2/\partial p}\right)$ in Figure 2 will be referred to as the value of insurance against disaster.

The statistical model of the previous section indicated that aggregate variance can be reduced in some circumstances by choosing more plots of land. Because the aggregate variance formula in (2) refers to variance per unit of land, the variance on the total hectares held by the farmer, N, can be restated following McCloskey's approach as

$$\sigma_a^2 = \frac{N^2\sigma^2}{p}\,[1+(p-1)r]. \qquad (3)$$

Choosing a larger number of plots reduces aggregate variance, *ceteris paribus*. If there are costs and inefficiencies associated with farming on dispersed plots, choosing a larger number of plots would likely reduce average yields, however. Average total yield on a land holding of N hectares may be represented by

Figure 2. The Tradeoff Between Average Yield and the Variance of Yield.



$$\mu = N\alpha \left({}^{N}/_{p} \right)^{\eta} \tag{4}$$

where η measures the percentage loss in yield as plots become more scattered, and α indicates the productivity of the farmer's resources and factors of production.

Both average yield and the variance of yield depend upon the farmer's choice of the number of plots.[6] Given a particular value of insurance against disaster, the optimal number of plots, p^*, is

$$p^* = N\left[\frac{I\sigma^2(r-1)}{\alpha\eta}\right]^{\frac{1}{1-\eta}} \tag{5}$$

where $\eta \neq 1$. Note that the larger the average correlation in yields, r, the smaller is the optimal number of plots. To the extent that yields and rainfall are highly correlated, the meteorological evidence and the relationship between p^* and r in (5) suggest that scattering of holdings will not occur in high latitudes. In arid, semi-arid, and tropical climates where correlation values decline rapidly over short distances, the optimal number of plots in (5) also increases as the average variance on individual plots, σ^2, increases. Thus where the localness of convective rain showers or orographic effects increases the variance of rainfall on any given plot, the incentive to scatter land holdings increases.

As the tradeoff between average yields and variance is valued more highly (I), one would expect a desire for more plots, i.e., risk-averse agents such as subsistence farmers and herders prefer scattering. The value of insurance against disaster likely depends not only on the farmer's aversion to risk but on how much household income varies with agricultural production. Households relying solely upon agricultural production will value insurance against disaster more than households which have reliable sources of off-farm income. Subsistence farming households are, therefore, more likely to diversify spatially.

Insights into the complementarity between spatial diversification and common property regimes emerge from the optimal plot equation (5). Where the loss in average yield due to scattered plots, η, is small, the incentive for more plots is stronger. For lands at the extensive margin, the value of η is likely small because access to dispersed areas is not prohibited physically or institutionally. Common property regimes on the extensive margin can reduce the transactions costs of managing scattered plots thereby reducing the loss in average yields due to scattering.

Technical progress and the modernization of agriculture (measured by α) diminish the number of optimal plots. Technological advances in crop varieties, animal genetics, irrigation, and management practices generate increases in average yields so that the optimal number of plots can be consolidated. As farms and ranches become more productive, incentives will emerge to reduce scattering, encourage enclosure, and possibly, privatize common lands.

Responses to Ecological Variability

Kenya

The Ngisonyoka Turkana in northwest Kenya herd camels, cattle, goats and sheep over 100,000 km^2 of arid and semi-arid range land (McCabe et al. 1988). These semi-nomadic people live in *awi*, which is a family unit of an adult male herder, his wives and children. During most of the year these family groups move within their tribal boundaries in search of forage. During the rainy season multiple *awi* will form a larger community or *adakar* and remain settled in one location until the local forage supply is depleted.

Spatial variability in rainfall within and across seasons produces dispersed microhabitats where the quality and quantity of forage varies. The Turkana respond to this environmental variability using two range management strategies. First, they divide their herds in the dry season by animal type according to the available forage: grazers (e.g., cattle) will feed on the remaining grasslands while the browsers (e.g., camels, goats) forage on more marginal lands. Secondly, the family unit is divided into multiple herding units and the herds are moved throughout the tribal boundaries in search of the appropriate forage for a specific type of animal. These sub-units of the family may not join one another until the onset of the rainy season.

In this harsh, unpredictable environment herd-owners rely on their perceptions of the spatial nature and intensity of rainfall to sustain their herds. Researchers traveling with the Turkana have noted significant variability in individual herd movement during any single year and between years. Flexibility in herd size and animal type as well as freedom of movement, increases the probability that the animals and the *awi* will survive until the next rainy season.

McCloskey's behavioral model (Equation 5) captures the grazing environment of the Turkana. The low spatial correlation in rainfall (r), the high risk aversion of subsistence pastoralists (I), the small loss in yield as plots become more scattered (η), and the low productivity of existing resources (α) produce a large, optimal number of plots for this grazing system. Arguably under current management practices the Turkana are achieving optimal levels of herd productivity subject to their environmental constraints.

Pastoral nomadism, like that practiced by the Turkana, is being displaced in some areas of Africa by commercial open-range ranching (Behnke 1984). These communally-managed grazing schemes produce greater incentives for water development and sustainable grazing practices than the nearly open-access system of the Turkana. But efforts to further intensify grazing management with fenced ranching have a predictable history. During the 1960s and 1970s externally-funded development projects were designed to replace African management techniques on open-range systems with more "modern" enclosure or fenced ranching. These efforts to enclose communally-managed grazing systems were rejected by the people they were designed to assist. Citing experiences in Uganda, Botswana and Kenya, Behnke states:

> "It is now clear that African pastoralists and open-range ranchers rejected all components of these projects which did not meet their immediate needs, and persistently rejected the use of fencing. Botswana and Maasai livestock producers cite a consistent set of reasons for this rejection. Fences, say the Botswana, would

> trap herds on ranches that were periodically untenable due to borehole breakdown, veldt fires, and localized drought. Maasai, on the other hand, stress the problems of erratic rainfall and insufficient resources on particular ranches. Like subsistence pastoralists, open-range ranchers rely on mobility as a technique for balancing localized deficiencies in resources needed by the herd. In this way they maintain within a wide geographical region a total livestock population far greater than that which could be sustained, *ceteris paribus*, by independent herds operated separately on small plots of land. (p. 278)

Privatizing and fencing the range land would not only require a sizable capital investment, but parcelizing open-range ranching would expose the herder to unacceptable levels of ecological uncertainty due to the spatial variability of resources and rainfall.

Mexico

Current modernization efforts in Mexico's agricultural sector focus on the privatization of the *ejidos* which control 48% of the agricultural land in the country.[7] The *ejido* is a common property regime which has its roots in the indigenous past of Mexico (Rincon Serrano 1980). Current privatization programs will legalize the renting and in some instances the selling of parcelized *ejido* lands to other farmers and investors. Corporations, both domestic and foreign, can now own these lands. The intent of these institutional changes is to modernize the *ejido* sector which is 30-50 percent less productive (measured as output value per hectare) than comparable private farms (Yates 1981).

There are two types of *ejido* land: parcelized and communal. The parcelized lands generally are used for crop production. These lands remain with the family and are divided among the heirs, thereby producing unproductive minifundia in many instances. Communal lands, particularly in the northern half of the country, are unfenced property used for grazing and forestry purposes where open access can be a problem.[8] It is noteworthy that parcelized lands as a percentage of total *ejido* lands range from less than 1% in Baja California Sur to 84% in Veracruz (Instituto Nacional de Estadistica 1988). Nationally, approximately 28% of the *ejido* lands are parcelized and subject to privatization. In the arid and semi-arid North Pacific region irrigated *ejido* land represents 45% of the agricultural lands in the region (not including communal lands). Yet this area represents only 5% of the *ejido* lands, parcelized plus communal. Only 3.5% of *ejido* lands at the national level are irrigated.

Meteorologically, there is no reason to expect correlation-distance functions for rainfall in Mexico to depart substantially from the literature reported earlier in this paper. Researchers at the Southwest Watershed Research Center, operated by the Agricultural Research Service of the U.S. Department of Agriculture, indicate that their data from the northern Chihuahuan desert is applicable to all of the North Pacific and North regions of Mexico (M.A. Weltz 1992, personal communication). These regions represent nearly 60% of the national land area controlled by *ejidos*. Published works specifically on northern Mexico by Hastings and Turner (1965) and Hastings and Humphrey (1969) support the proposition of significant rainfall variability across space.

Given the predominance of common land in *ejidos* located in northern Mexico where high variability in rainfall prevails, our interpretation of McCloskey's behavioral model yields several insights into the likely outcome of new reforms of the *ejido* sector. First, it is clear that not all of the 95 million hectares of *ejido* land will be privatized, at least not in the foreseeable future. Only 27% of these hectares is parcelized, an institutional arrangement which facilitates the privatization process. However, the higher transactions costs of privatizing the larger blocks of communal grazing lands will discourage investors. Secondly, herders on non-irrigated *ejidos* which experience convective storms in the critical growing months of June, July and August will continue to favor scattering under a common property regime. At least in the northern half of Mexico, we see no present economic incentive for investors to lobby the government to include communal lands in the privatization scheme. A single individual could capture the localness feature by controlling a large expanse of grazing land on the extensive margin, yet higher returns on investments in other areas of the economy will discourage such decisions. Thirdly, as noted earlier in our discussion of Equation 5, the introduction of modern technology can encourage the enclosure of the commons. For this reason we anticipate that the irrigated *ejidos* will be the first *ejidos* to be privatized. In this case, risk averseness is lowered, yield variability is reduced by supplemental irrigation, the use of fertilizer is more viable, and the incentive to produce high value crops is enhanced. In the irrigated *ejidos*, according to McCloskey's model, the optimal number of plots for economic sustainability is less than the number for economic viability in non-irrigated *ejidos*.

Concluding Remarks

Natural resource endowments matter in the study of property regimes. As in Africa, existing property regimes can be a human response to variable ecological conditions. Extensive margin lands, characterized by low mean productivity and high variances in yield, constrain the institutional choice set for farmers and herders. Community-oriented or risk-spreading regimes may be preferred to other institutional arrangements in these harsh environments. As has been shown in Kenya and Mexico, communally-managed range lands may be a rational and efficient response to existing resource conditions. Blanket condemnations of common property may reflect a limited understanding of the risky environment farmers and herders face in many areas of the world. Governmental efforts to improve the economic status and resource base of grazing lands on the extensive margin must understand and take account of the ongoing rational responses of herders to their natural environment.

Endnotes

1. Bromley argues that the functional relationship may be written as: Property Right = f(Economic Yield).

2. It is recognized that there are other management means, besides access to geographically dispersed plots of land, for spreading risk across a grazing operation. For example, Binswanger and Rosenzweig (1986) have demonstrated how farmers use marriage contracts to forge alliances with families in other climatic regions.

3. An orographic effect implies conditions where rain is produced when a mountain or mountain range deflects moisture-laden wind upward.

4. See Hendricks and Comer, 1970 and Stol, 1972 for other higher latitude examples of correlation-distance relationships.

5. Assuming a well behaved utility function for the farmer, the value of insurance against disaster, I, can be conceived of as the slope of an indifference curve tangent to the mean-variance frontier. The point of tangency represents the combination of mean and variance which produce the highest level of utility for the farmer. The slope of the mean-variance frontier, $d\sigma^2/d\mu$ is simply $-\frac{\partial\mu/\partial\sigma^2}{\partial p/\partial p}$. Equating the slope of the mean-variance frontier with I and solving the optimal number of plots gives equation (5).

6. Because the productivity parameter, α, does not enter the variance equation (3), productivity increases have no effect on the variance of yield. Whether increased productivity increases or decreases the variance of yield is an empirical question which depends upon the nature of the technology adopted.

7. An in-depth evaluation of privatization efforts in Mexico's *ejido* sector is provided in Thompson and Wilson, 1994.

8. Current coalition building behavior by *ejidatarios* in response to spatial variability is described in Wilson and Thompson, 1994.

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