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Stochastic Wealth Dynamics and Risk Management Among A Poor Population

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Comments appreciated

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Abstract: The literature on economic growth and development has focused considerable attention on questions of risk management and the possibility of multiple equilibria associated with poverty traps. We use herd history data collected among pastoralists in southern Ethiopia to study stochastic wealth dynamics among a very poor population. These data yield several novel findings. Although covariate rainfall shocks plainly matter, household-specific factors, including own herd size, account for most observed variability in wealth dynamics. Despite longstanding conventional wisdom about common property grazing lands, we find no statistical support for the tragedy of the commons hypothesis. It appears that past studies may have conflated costly self-insurance with stocking rate externalities. Such self-insurance is important in this setting because weak livestock markets and meager social insurance cause wealth to fluctuate largely in response to biophysical shocks. These shocks move households between multiple dynamic wealth equilibria toward which households converge following nonconvex path dynamics. The lowest equilibrium is consistent with the notion of a poverty trap. These findings have broad implications for the design of development and relief strategies among a poor population extraordinarily vulnerable to climatic shocks.

I.   Introduction

A vast economic literature on risk management rests, explicitly or implicitly, on the classic Friedmanite permanent income hypothesis. Studies of portfolio management, consumption smoothing, social insurance, and the like all depend on the canonical assumption that stochastic income realizations are drawn from a stationary income distribution, leading to consumption smoothing off a stable asset base. The possibility of asset accumulation connects this literature to the immense literature on the theory and empirics of economic growth.

In much of the world, however, income flows vary largely due to variability in the productive asset stock. In such cases, households may intentionally destabilize consumption in order to conserve assets needed for future consumption (Carter and Zimmerman). Such behaviors become especially important if there exist thresholds such that wealth dynamics differ above and below the threshold, creating history dependence in household welfare measures (Azariadis and Drazen, Banerjee and Newman, Carter and May, Dasgupta, Dasgupta and Ray).

If multiple dynamic wealth equilibria indeed exist, policy can play a significant role in helping move people out of prospective poverty traps and in helping keep them from falling from high to low-level equilibria. However, the appropriate policies to follow depend on several crucial, inherently empirical questions. First, is wealth risk largely covariate or idiosyncratic? If it is covariate, then transfers from outside the system are essential to provide effective safety nets, while if risk is largely idiosyncratic, creating effective internal finance (credit and insurance) systems are the most appropriate strategy. Second, do existing institutions, such as resource tenure regimes, foster negative externalities that might adversely affect wealth dynamics? Among the population we study, policymakers have long assumed the existence of a "tragedy of the commons" attributable to grazing land held as common property. Third, what

accounts for the threshold points inherent to multiple equilibrial systems, where are they in wealth space, and what do these imply about the design of safety net policies intended to prevent people from falling into persistent poverty? Each of these questions is of broad relevance in economics, yet they are all fraught with a variety of empirical problems in most settings. In particular, among most populations, the wide array of feasible livelihood strategies makes meaningful measurement and aggregation of assets difficult, if not impossible, shocks are not often readily observable, and analysts rarely have sufficient longitudinal observations to get a good sense of the dynamics of the system.

We explore these issues using a unique, 17-year panel data set collected among a population that depends almost entirely on a single stochastic asset for its income and sustenance in a land subject to frequent, severe climatic shocks. The pastoralists who inhabit arid and semi-arid lands (ASAL) of east and southern Africa are among the world's poorest populations. Livestock comprise the overwhelming share of their limited wealth. Extensive livestock production in the ASAL is characterized by low rates of marketed offtake, aperiodic system crashes in which half or more of the aggregate herd commonly perishes, and complex systems of interhousehold livestock gifts and loans to help rebuild herds decimated by climatic or epidemiological shocks or by raiding. The volatility of the system partly reflects the multiple roles livestock play in this setting, serving as a source of food (milk, meat and blood), a provider of services (manure, traction and transport), an object of status, and a store of wealth. Moreover, livestock help regulate ASAL rangeland ecosystems, so livestock mortality and productivity may be endogenous to pastoralist husbandry decisions. These characteristics make this region uniquely appropriate for the study of stochastic wealth dynamics and risk management behavior and the implications for development policy.

II. Livestock, Risk and Pastoralist Behavior

ASAL households hold livestock in part because these assets have relatively high expected returns, albeit matched by high variability in returns, and because livestock provide insurance against future income shocks (Dercon, Desta et al., Fafchamps and Gavian). In pastoral systems, livestock are so fundamental to survival that herd size is typically a direct correlate of both wealth and status (Swift). Nonetheless, livestock capital is commonly exposed to the risk of partial or complete loss.

The existing literature emphasizes ASAL livestock cycles running from drought to range degradation, destocking of animals, range recovery and restocking of animals, followed by the next cycle of drought and recovery (Fafchamps, Livingstone, Swift). A key factor in these livestock cycles is the overexploitation of available forage, often hypothesized to occur due to overgrazing and other externalities that potentially arise from common or open access to rangeland. These posited externalities can greatly magnify the effect of droughts on livestock (Coppock, de Leeuw and Tothill, Fafchamps, Sanford, Turton). Much pastoral risk is therefore conventionally considered covariate, in the sense that it is collectively experienced. Livestock losses during these cycles can be massive (up to 50-80% losses for cattle and 30% for sheep and goats), and these cycles strongly determine the effectiveness of risk-coping strategies among the ASAL poor, whose access to financial savings, credit, and insurance is extremely limited.

Mortality risk is aggravated by underdeveloped livestock marketing systems in extensive pastoral areas (Barrett et al., Fafchamps and Gavian). During times of drought, the livestock-grain terms of trade often collapse with the herd, especially when the proximate cause is drought that also reduces grain supply. The combination of poor market integration and drought can

thereby impede the self-insurance role of livestock if falling real livestock prices induce households to retain livestock despite reduced income and consumption, depressed animal productivity, and increased chance of mortality if the animals remain locally (Cossins and Upton 1988, Fafchamps et al.). These effects, along with a desire to smooth asset stocks over time so as to smooth intertemporal consumption (McPeak), help explain why ASAL pastoralists appear surprisingly autarkic in the face of variable returns and unstable consumption.

These factors signal a potentially important idiosyncratic component to pastoral risk. Small herds may not be able to cope as well as large herds when faced with tough times (Tacher). If poor households have fewer consumption options and therefore rely disproportionately on their livestock for milk (and/or blood), their livestock are likely to become weaker and exposed to greater risks during drought. Sieff and Upton each observe that East African pastoralists with large herds milk 35-45% of their cows, while those with small herds milk 65-75%, which in times of stress adversely impacts calf growth and survival. To the extent that households differ in their ability to mitigate and treat disease (Sieff), through purchase of veterinary supplies for example, or in their access to formal or informal credit markets, to livestock markets or to herding labor needed to move herds to better forage distant from settlements (Little), then the risks posed by livestock disease may also be significantly idiosyncratic. Thus even if covariate climatic events and aggregate stocking rates on common property rangelands propel livestock cycles, as long as households differ in their ability to cope with or mitigate these risks there are likely to be dramatic differences in the damage sustained across pastoral households.

This may have significant effects on wealth distributions and dynamics among ASAL pastoralists. Some argue that the poor suffer disproportionately high livestock mortality rates

(Sieff) or that rich pastoralists have other options for smoothing consumption in the face of identical livestock mortality experiences, and thus sell livestock less frequently than do poor pastoralists (Upton). Others conjecture that in spatially segmented markets the rich may speculate on fluctuating livestock prices (Fafchamps), or that the poor haven't sufficient liquidity to accumulate high-risk, high-return assets such as livestock (Dercon). The common implication is that rich households accumulate livestock while poorer households lose animals and exit the pastoral system over time. In so far as livestock mortality risk is indeed idiosyncratically experienced by pastoralists, one would therefore expect this to manifest itself in nonlinear accumulation patterns that appear dependent on *ex ante* household wealth. Since pastoral systems and their participants are increasingly stressed due to loss of spatial refugia to town growth, increased area under cultivation, gazetting of parks and protected areas, and violence (Coppock, Desta), the potentially *ex ante* wealth-differentiated nature of livestock mortality, marketing, and transfer patterns, and thereby of herd accumulation dynamics has strong implications for the survival of the poorest households in pastoralist systems.

III.   Data

Desta compiled 17-year (1980-97) cattle herd histories for a set of 55 randomly selected households drawn from four communities (Arero, Mega, Negelle and Yabello)[1] on the Borana Plateau in southern Ethiopia.[2] Because 16 of the sample households were formed within the 17 year period, this is an uneven panel of data, with 833 total observations. The 1980-97 period includes two different, major droughts during which large numbers of livestock perished. Desta

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[1] Desta included all rural households within 35km of these small towns in the sampling frame. The population of these towns ranged from 4,100 (Arero) to 25,000 (Negelle). These towns are 50-100km apart, and rainfall and natural resource endowments vary across the sites.

used a stratified random sampling design, collected the data using detailed interviews held with entire extended families and relied on collective recall to construct the panel data set.[3] The data include annual recall on mortality, marketing, gift and loan, slaughtering, and calving, as well as on labor availability, rainfall, and aggregate local stocking rates.[4]

The importance of cattle mortality as a lost opportunity in this setting is perhaps best reflected by Desta and Coppock's estimates that asset losses due to cattle mortality for the entire Borana community over the 17 year period total about $300 million, easily an order of magnitude greater than external transfers into these communities and nearly three times their aggregate cash income over the period. Development agencies are now working in the region to reduce losses due to livestock mortality through improved husbandry and range management, diversification into less risky assets, improved livestock marketing systems, etc. But appropriate targeting of interventions depends fundamentally on an improved understanding of the sources of asset risk and pastoralists' established response to shocks, perhaps especially among the poorest households.

The Boran hold their almost entirely in the form of cattle.[5] They manage their livestock in two sub-herds, a milking or *warra* herd and a dry or *fora* herd.[6] The *warra* herd consists of milk cows and calves and is generally kept near the settlement on common property or household-specific land, while the *fora* herd consists of older immature cattle, dry cows and bulls and is

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[2] The Borana Plateau is located about 600km south of Addis Ababa. For more details on this region of Ethiopia see Desta, Coppock, and Cossins and Upton 1987.

[3] Changes in cattle herds register prominently among ASAL pastoralists, thus herd history data among these peoples typically prove reliable (Assefa, Ensminger, and Turner).

[4] Respondents' perceptions of rainfall and stocking rates were measured on a five-point ordinal scale.

[5] Among the Ethiopian Boran we study, none own land (which can only be owned by the state in Ethiopia), there are few nonagricultural options and thus scant nonagricultural capital, less than two percent hold bank accounts of any sort, and cattle account for more than 93 percent of total tropical livestock units in any given year (Cossins and Upton 1987, Desta 1999). A tropical livestock unit (TLU) represents approximately 250 kilograms live weight, with 1 TLU = 1 cattle = 0.7 camels = 10 sheep or goats.

[6] This background paragraph draws heavily on Coppock, Cossins and Upton (1987, 1988a, and 1988b), and Desta. Note that *fora* herds are not entirely dry since a few milk animals are included to sustain the migrating herders.

therefore more mobile and better adapted to long-range migration in search of grazing during dry season and drought. Milk from the *warra* herd provides the mainstay of the Borana diet and most cash incomes are based on sales of cattle and small quantities of milk and butter. As in other pastoralist systems, the Boran rely on exchanging cattle for grain for their survival when the herd is unable to produce sufficient milk. And like most ASAL pastoralist systems, the Boran face prominent weather-related risks and poorly integrated livestock markets. Disease and wildlife predation is somewhat less severe of a problem on the Borana Plateau than elsewhere in the east African ASAL, with most livestock mortality attributable to starvation or malnutrition-related disease during periods of calamity.

The aggregate data reveal several patterns of interest. Median household herd size was 58 cattle in 1980-81 but only 29 in 1996-97, having dipped as low as 22 head in the drought year of 1992-93 in a system exhibiting a classic cattle cycle with downward drift (Figure 1).[7] The steady decrease in herd sizes appears likewise as a leftward shift of the cumulative herd size frequency distribution, with the five-year distribution for 1980-84 first-order dominating that for 1986-90, which in turn first-order dominates the 1992-97 distribution (Figure 2).[8] As Coppock points out, steady human population growth in the area has reduced per capita livestock holdings. Boran pastoralists are getting steadily poorer in livestock terms. Both culturally and economically, reduced livestock wealth means diminished status and living standards, especially if other opportunities and productive activities are not available. The increased stress in this system is readily apparent.

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[7] By way of comparison, average herd sizes for full-time operators in extensive cattle systems in the contemporary western United States are 236 head of cattle and 212 head of sheep (Peterson and Coppock). By the standards of other extensive grazing systems in semi-arid Africa, however, Boran herd sizes seem to be of average to slightly higher than average size, with median herd sizes have fallen to roughly the 2 or 3 TLU/person threshold that maintains herd food security while trekking (Pratt and Gwynne, Simpson and Evangelou, Coppock).
[8] This understates the overall decline in mean herd sizes since these data derive from a 1997 survey of pastoral households and any herding households as of 1980-81 who exited the system prior to 1997 are therefore omitted.

Marketed offtake is extraordinarily limited, with annual gross sales peaking at just 3.3 percent of beginning period herd size and mean net sales hovering below two percent throughout the period. Average household gross cattle sales have a simple bivariate correlation coefficient of 0.578 with average household cattle mortality, indicating that livestock sales and losses tend to occur contemporaneously. Nonetheless, mortality, not marketing, is the dominant regulator of herd sizes, with mortality greater than net sales every one of the seventeen years, and routinely reaching or exceeding 25-35 percent of the aggregate herd in drought years. Moreover, the correlation coefficients between livestock prices and mortality in these data are very modestly negative, -0.05, -0.04, and –0.02 for calves, bulls, and cows, respectively. The Borana pastoralists do not appear to enjoy the income-stabilizing negative output-price covariance (equivalently, a positive mortality-price covariance) commonly found in the crop agriculture. This seems attributable to both livestock's primary role as an asset whose productivity affects its price, and to the poor state of livestock markets in the ASAL (Barrett et al.).

IV.   Livestock Mortality Experience Among The Borana

The data permit investigation of whether pastoralists' cattle mortality experience can be explained by commonly experienced shocks associated with rainfall and stocking rates, or whether there are significant idiosyncratic, or household-specific, factors that account for mortality experience. Might seemingly distributionally-neutral shocks (e.g., low rainfall) have wealth-differentiated mortality effects? Does growth in individual household herds exert negative externalities on neighboring herds due to tragedy of the commons effects?

Before introducing the mortality models we estimate, we should comment on the use of mortality as a proxy for pastoral risk. Mortality is the extreme manifestation of the risks

pastoralists face. There are of course substantial declines in health and productivity that precede

an animal's death. These changes in productivity (e.g., milk production, weight, conception rate,

etc.) are likely to be a more common source of pastoral risk and they may respond somewhat

earlier to alleged overstocking on common property grazing areas. Unfortunately, the data do not

permit us to investigate these more moderate manifestations of pastoral risk. Nonetheless, since

cattle account for well in excess of 90 percent of wealth among the Boran (Assefa, Cossins and

Upton 1987, Desta, Desta and Coppock) and marketing is so modest, mortality and herd

dynamics provide a reasonably proxy for wealth dynamics and pastoral risk among the Boran.

(a) Estimation and hypothesis testing strategy

We estimate variants of a simple mortality model taking as its dependent variable the

total cattle[9] mortality experience of household i in location j over the course of year t (M_{ijt})

expressed as a proportion of beginning period household herd size (H_{ijt}). This dependent variable

is therefore a simple household herd mortality rate, $m_{ijt} \equiv M_{ijt}/H_{ijt}$. Regressors include covariate

and idiosyncratic variables as follows:

(1)
$$m_{ijt} = \alpha_0 + \alpha_1 m_{jt} + \alpha_2 H_{ijt} + \alpha_3 H_{ijt}^2 + \sum_{r=1}^{2} \alpha_{4r} H_{ijt} R_{rjt} + \sum_{r=1}^{2} \alpha_{5r} H_{ijt}^2 R_{rjt}$$
$$+ \boldsymbol{\theta}_v \cdot \mathbf{V}_v + \boldsymbol{\theta}_h \cdot \mathbf{V}_h + \varepsilon_{ijt}$$

where

$$m_{jt} \equiv M_{-ijt} \big/ H_{-ijt}$$
$$M_{-ijt} = \frac{1}{n_j - 1} \sum_{k \neq i} M_{kjt}$$
$$H_{-ijt} = \frac{1}{n_j - 1} \sum_{k \neq i} H_{kjt}$$

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[9] Total cattle mortality includes mortality of adults, immatures and calves.

and where R_{rjt} (r=1,2) is a rainfall dummy variable (R_{1jt}=1 if high rainfall and 0 otherwise; R_{2jt}=1 if average rainfall and 0 otherwise; R_{1jt}=R_{2jt}=0 thus implies low rainfall),[10] and $\mathbf{V_v}$ and $\mathbf{V_h}$ are vectors of village and household dummies, respectively. Village dummies control for village fixed effects including pasture quality and other unobserved community-specific determinants of household-level mortality experience (e.g., disease, wildlife predators, etc.). The time-invariant household-specific dummy variables control for relevant unobserved household characteristics such as animal husbandry skills, labor availability and pastoral experience. Since m_{jt} represents the average mortality rate for all households (excluding household i) in location j[11] over period t, if mortality risk is perfectly covariate, then β_1 should be one (i.e., each household has the same mortality rate) and there should be zero effect from household-specific variables such as beginning period herd size, H_{ijt}, and the household dummies, $\mathbf{V_h}$. The strong covariate risk hypothesis is thus embodied in the null hypothesis α_1=1 and α_i= $\boldsymbol{\theta_h}$=0 $\forall$ i>1 versus the alternative α_1< 1, or $\boldsymbol{\theta_h}$ or $\alpha_i \neq 0$. Failure to reject this strong null hypothesis would signal that mortality experience is effectively covariate across households within a given community and year.

A serious potential problem with the above model is that m_{jt} is likely to be simultaneously determined with m_{ijt}. An alternate specification replaces m_{jt} with rainfall dummy variables, R_{rjt} (r=1,2) and exogenous beginning period stocking rates, captured by H_{jt} and H_{jt-1}, where H_{jt} is the average herd size[12] for location j at time t (again excluding household i).[13] Thus,

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[10] Rainfall was collected on a five point scale, but we lumped "high" and "very high" into one category and "low" and "very low" into another. Low rainfall is the reference regime.

[11] Due to the small number of households surveyed in any given site, we use just the four study centers (Arero, Mega, Negelle, and Yabello) to define communities. The Boran have a complex system of hierarchical units of resource control (Coppock 1994), with multiple *madda* and dozens of *arda* per study center in these data.

[12] There are two justifications for using the average community herd size (household i excluded) instead of the total community herd size. First, the panel of data is unbalanced (16 of the 55 surveyed households were formed during the 17 year span of the data), introducing imprecision into an estimate of total community herd size. Second and more importantly, estimating a population (village) *sum* based on sample (surveyed households) data introduces bias

$$m_{ijt} = \beta_0 + \sum_{r=1}^{2} \beta_{1r} R_{rjt} + \beta_2 H_{jt} + \beta_3 H_{jt-1} + \sum_{r=1}^{2} \beta_{4r} H_{jt} R_{rjt}$$

(2)
$$+ \beta_5 H_{ijt} + \beta_6 H_{ijt}^2 + \sum_{r=1}^{2} \beta_{7r} H_{ijt} R_{rjt} + \sum_{r=1}^{2} \beta_{8r} H_{ijt}^2 R_{rjt}$$

$$+ \theta_v \cdot \mathbf{V}_v + \theta_h \cdot \mathbf{V}_h + \varepsilon_{ijt}$$

In recent years, the range science literature has vigorously debated the relative importance of stochastic rainfall and herd stocking rates in driving pastoral mortality patterns, disputing whether overgrazing is inevitable in the ASAL due to common property management problems or whether climatic shocks regulate herd size before resource availability per animal become a binding constraint (Behnke et al., Desta and Coppock, Ellis and Swift, Hullen, Majok and Schwalbe, McCabe and Ellis, McPeak, Sanford 1982, Scoones et al., Westoby et al.). The estimated relationships between stocking rates and rainfall ($\beta_1 - \beta_8$) contribute to that debate.

Of more direct relevance to the questions motivating this paper, a test of the joint exclusionary restriction on H_{jt} and R_{rjt} and their interaction terms—i.e., that these factors jointly have zero effect on mortality—is a weak-form test of the no-covariate-risk null hypothesis, in contrast to the previous, strong-form test of the covariate risk hypothesis. The complementary, joint exclusionary restriction on the idiosyncratic variables – $\beta_i = \theta_h = 0 \ \forall \ i > 4$ – is likewise a test of the no idiosyncratic risk null hypothesis. Rejection of only one or the other exclusionary restriction null would imply asset risk that is effectively solely due to covariate or idiosyncratic factors. Rejection of both joint null hypotheses would indicate that livestock mortality risk is attributable to both covariate and idiosyncratic factors. This would suggest that widespread

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into the standard errors, but estimating a population *average* based on sample data does not. Alternatively, while the variance of an estimated population average goes to zero asymptotically, the variance of an estimated population sum need not.

[13] We report estimates based on the average of herd sizes from the surveyed households in the community, excluding the household associated with the observation in question. The qualitative results are unchanged when we replace this continuous measure of community herd size with the ordinal stocking density measures – ranging from

drought or high stocking densities may induce greater mean mortality, but that herders'

experience differs systematically around this common mean mortality response.

The presence and importance of stocking rate externalities can likewise be tested using

the specification in equation (2). If the mortality rate increases less than proportionately with *ex

ante* herd size, then a household's own expected end-of-period wealth is increasing in its herd

size; larger *ex ante* herds are expected to yield larger *ex post* herds, as one would expect. But if

the mortality rate is also increasing in the size of the overall local herd, H_{jt}, then each

household's increased herd size imposes a negative externality on the other households in the

community, presumably through competition for forage and water, or increased risk of disease

transmission or cattle raiding. So by testing the joint null hypothesis $\beta_2 = \beta_3 = \beta_{4r} = 0$ ($r=1,2$) and

$\beta_5 = 1$ versus the alternate β_2, β_3 or $\beta_{4r} > 0$ ($r=1,2$) and $\beta_5 < 1$, one can determine whether stocking

externalities exist.

We focus additionally on the mortality experience on calves. Calves are the highest

return and highest risk component of a herd, and past researchers have found that calf mortality

appears negatively correlated with wealth even when total mortality is not (Cossins and Upton

1988, Desta, Sieff). So we reestimate models (1) and (2) using as the regressand calf mortality

rates, $cm_{ijt} \equiv CM_{ijt} / C_{ijt}$,[14] and $cm_{jt} \equiv CM_{-ijt} / C_{-ijt}$ as a regressor.

Since mortality experience is nonnegative, the models estimated here are subject to

censoring. Specifications (1) and (2) are left censored at zero for both total mortality and calf

mortality. Note that mortality rates are not bounded from above at one's *ex ante* herd size

because livestock transfers, purchases and sales can occur throughout the year.

1(very high) to 5 (very low) – that Desta collected from each household for each year. These two variables are
highly correlated.

[14] C_{ijt} is the number of calves born to household i in location j at time t, and CM_{ijt} is the household's calf mortality
experience.

(b) Estimation results: covariate asset risk without tragedy of the commons effects

Table 1 presents estimates of the four models for total cattle mortality.[15] There is indeed a positive and statistically significant association between household and community cattle mortality, although it is far from the one-for-one relation imposed by the strong-form test of exclusively covariate risk. A one percent increase in the community mortality rate implies an expected increase in a household's mortality rate of only about 0.55 percent. Moreover, household herd size exerts a statistically significant effect on mortality experience, both on its own and interacted with the rainfall dummies, even when controlling for community level mortality. We can overwhelmingly reject the strong covariate risk hypothesis in these data.

In the models that use rainfall dummies and community herd sizes instead of community mortality experience, thereby avoiding potential simultaneity bias, mortality rates fall significantly, by 25 and 20 percent for high and average rainfall years, respectively, relative to low rainfall years. The likelihood ratio test statistic of the exclusionary restriction that the rainfall dummies, cluster herd size, lagged cluster herd size, and cluster herd size-rainfall interaction terms have zero effect is 65.3, with a p-value less than 0.001. We can plainly reject the no covariate risk null. Of the covariate variables, it appears that rainfall shocks especially matter to pastoral households' livestock mortality rates on the Borana plateau.

Perhaps surprisingly, we find no statistical support for the claim that community average stocking rates affect mortality, either independently or jointly with rainfall. Desta and Coppock, studying the same system, found that stocking rates affect mortality in some locations and for some classes of animals when interacted with rainfall, but they did not separate out the effects of

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[15] The estimates of θ_h (the coefficients on the time-invariant household specific dummy variables) are not displayed to conserve space. The combined effect of these variables is however analyzed later in this section.

one's own herd from the effects of others' herd. We tried pooling the two and then found that

indeed total stocking rates, including one's own herd, have a (weakly) statistically significant,

positive effect on mortality under some (not all four) specifications, a result matching Desta and

Coppock's.[16] This suggests that studies that fail to distinguish between a household's own herd

and others' herds may be misidentifying costly self-insurance (mortality is increasing in own *ex*

ante herd size, as we discuss below) as stocking rate externalities.[17]

A simple nonparametric (locally weighted, nearest neighbor) regression of household-

level mortality rate on community average herd size confirms this finding unconditionally

(Figure 3a). There is no significant relation between household-level herd mortality rates and the

community stocking rate ranges observed in this sample. By contrast, Figure 3b shows there is a

strong, positive, unconditional relationship between mortality rates and herd sizes within a

household. If our evidence is any indication, the extant literature on rangeland overstocking may

be conflating the effects of own herd size, which are surely internalized by the herd manager,

with the effects of others' herd size, from whence widely claimed "tragedy of the commons"

effects emanate (Hardin). This carries important implications for range management policy, as it

suggests that overgrazing is less the product of inefficient tenurial institutions than of missing

insurance markets that induce costly self-insurance in the form of herd accumulation.

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[16] It is unlikely but possible that our definition of "community" biases our results in favor of not finding stocking
rate externalities. Because of the small number of households in the data set, we aggregate households at the level
of the four study centers, not by more localized grazing units (*arda, madda,* or *olla*). If resource control is strictly
controlled within these smaller units, so that animals from one *arda* within a study center can never use the grazing
or watering areas of another *arda* within the study center, and if herd sizes across contiguous grazing units are
uncorrelated with one another, then it is conceivable that herd size within one *arda* in a study center could increase
without there being an increase in either stocking density or mortality in another *arda* within the same study center.
In such a case, our estimates of stocking rate externalities would be biased downwards. Likewise, if area accessed
increased with aggregate herd size, then our headcount measures would not accurately capture stocking density
pressures. We partly tested for these potential sources of bias by replacing H_{jt} with an ordinal measure of individual
households' perceptions of the stocking rates they faced each year, which would presumably capture finer scale
resource management and possible intertemporal variation in grazing areas. The results are qualitatively identical to
those reported here.

Why does neighbors' herd size not seem to affect a household's expected livestock mortality? Unfortunately, the data do not permit direct inference on this important question. We can nonetheless identify three prime candidate explanations for this observation.

First, respondents told us that as stocking rates increase in the more concentrated *warra* areas they sometimes move pregnant, even lactating cows and young immatures (2 or 3 year olds) to the *fora* herd to reduce localized pressure, they move more frequently and to more distant grazing and watering sites, they replace young herders with more experienced adult male herders who can better manage the herd in time of stress, or they cut and carry forage and supplement with crop residues, food aid and other feed sources. Part of the story thus seems to be endogenous cattle husbandry responses that mitigate mortality experience. We have no data on these endogenous responses and therefore cannot control for them.

Second, the recent literature on "non-equilibrial" pastoral systems emphasizes that extraordinary variability in environmental conditions, particularly rainfall, may break down the closely coupled plant-herbivore interactions that characterize equilibrial systems so that the system becomes dominated by rainfall-driven variability more than by feedback effects from herd stocking density (Behnke et al., Ellis, Ellis and Swift, Sanford 1982, Scoones, Westoby et al.). In this view, overgrazing is not a problem because plant biomass is driven primarily by erratic rainfall, not by the effects of livestock grazing. The implication is that herd dynamics can be explained by rainfall patterns, while stocking rates exert no significant effect on herd growth or mortality. The semi-arid Boran Plateau we study, however, has somewhat greater and more stable rainfall than the drylands to which proponents argue non-equilibrial pastoral systems theory applies (Desta and Coppock). Moreover, our evidence indicates that own herd size

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[17] Because we only study cattle mortality patterns, our data do not permit the stronger claim that higher stocking rates do not affect livestock productivity due to externalities.

matters to one's herd dynamics, even if others' herd size does not. Furthermore, the clear cyclical pattern evident in Figure 1 is more consistent with the limit cycles typical of equilibrial systems than with the chaotic patterns observable in non-equilibrial ones.

Third, the absence of cross-sectional mortality externalities may be partly attributable to effective management of common property range resources. Although every Boran pastoralist has the recognized right to graze his livestock anywhere he likes in the ethnic group's territory, the Boran's lands are divided into districts (*madda*) organized around one or more permanent well complexes. These wells – which provide about 84 percent of total accessible dry season water (Helland) – are owned, operated and maintained by clans, employing a sophisticated management system founded on careful, cooperative organization of labor for water lifting from those wells (Coppock). Since water is the most limiting resource in dry periods when herds suffer stress, these structures necessarily tie households and classes together and appear to foster cooperation in resource management of the sort described by Baland and Platteau or Ostrom.[18] Hardin's claim that "freedom in the commons brings ruin to all" does not square with the present evidence. Cooperative resource management regimes can and do emerge in places such as the Boran plateau, dampening, if not eliminating, cross-sectional externalities of the sort implied by the familiar "tragedy of the commons". Of the three candidate explanations for the absence of any cross-sectional stocking rate externalities, this one strikes us as the most compelling, although we have no formal means to test among these hypotheses.

(c) Estimation results: idiosyncratic asset risk

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[18] The poor typically provide most of the (uncompensated) labor to lift the water that allows the wealthy to maintain larger herds. Larger herds commonly get placed at the back of the watering queue, which may lead to higher attrition in larger herds.

Herd mortality risk plainly has a significant idiosyncratic component. The likelihood ratio test for the exclusionary restriction that idiosyncratic variables have no effect on mortality is 135.1 (p<0.001) for model (2). The household dummy variables (i.e., the $\mathbf{V}_h$ vector) capture time-invariant unobserved characteristics such as husbandry skills, labor availability, education, etc. A third exclusionary restriction that these dummy variables have zero effect on households' livestock mortality experience sheds more light on household-specific livestock mortality risk. The likelihood ratio test for this restriction is 83.6 (p<0.001) for model (2).

While there may not be cross-sectional stocking rate externalities, own herd size is positively and statistically significantly related to own mortality experience. This may pick up a decline in the ratio of labor to herd size that means less care per animal, greater susceptibility to animal disease transmitted within larger herds, or it could reflect the fact that larger herds often get pushed to the back of the watering queue at cooperatively managed deep wells on the plateau (Coppock 1994). Whatever the mechanism(s), both models (1) and (2) indicate that the addition of about 40 head of cattle, equivalent to an upward shift of about a tercile of the herd size distribution, increases one's expected mortality rate by ten percent in a low rainfall year. Higher rainfall mitigates the expected effects of herd size on mortality, which suggests that perhaps the water queuing story plays an important role in differential mortality, just as the resource management regime likely helps explain the absence of any cross-sectional stocking rate externalities.

A key point is that the coefficients relating *ex ante* herd size to mortality imply mortality loss of less than one head for each animal added to the herd, no matter the herd size or rainfall state. For example, in the low rainfall state at the sample median herd size of 36 cattle, adding one animal at the beginning of the period only increases expected mortality over the ensuing year

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by 0.12 animal. Consequently, larger *ex ante* herds imply larger *ex post* herds. The own herd size-livestock mortality relationship appears concave in shares, peaking at about 55 percent of herd at the very high level of 375 head of cattle, which falls above the 98th percentile in the cumulative distribution over the sample period and exceeds any household's herd size since the terrible 1991-92 drought. The implication is clear. When consumption comes primarily from livestock holdings, maximizing herd size makes sense, even if it increases expected mortality. In the face of considerable, frequent exogenous shocks due to rainfall and other causes (e.g., disease, predators), self-insurance through herd accumulation may be costly, but it is the most effective way to survive wealth shocks and to assure future consumption (McPeak and Barrett).

Pastoralist households' calf mortality experience is qualitatively identical to that of the herd as a whole (Table 2). Own herd size significantly affects calf mortality, while expected household calf mortality rates increase at about half the rate of mean community calf mortality rates, all else held constant. The likelihood ratio test statistics of the covariate variables exclusionary restriction for (2) is 152.5 (p<0.001), suggesting that covariate factors affect calf mortality rates.[19] The likelihood ratio test statistic for the household-specific variables exclusionary restriction is 562.9 (p<0.001), underscoring the heterogeneity of wealth dynamics even among a poor population exposed to a common set of exogenous, driving factors, such as rainfall and range conditions.

Together, these results suggest both covariate and idiosyncratic mortality risk are at play in the wealth dynamics of Borana pastoralists. Generalized drought seems the primary source of covariate risk, since community-level stocking rates have no statistically significant effect on

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[19] One cannot reject the no covariate risk null hypothesis when either the whole herd or calf mortality models are estimates in levels rather than rates. The likelihood ratio test statistic of the exclusionary restriction that the rainfall dummies, cluster herd size, and cluster herd size-rainfall interaction terms jointly have zero effect has a p-value in excess of 0.15 in both cases. Detailed results of the levels regressions are available from the authors by request.

herd sizes. Yet there remains considerable inter-household variation in livestock mortality experience associated with both *ex ante* household herd size and unobserved individual household characteristics. So the challenge of pastoral risk management extends far beyond responding to climatic variation.

V.   Livestock Marketing And Transfers Among the Borana

Mortality is the dominant regulator of Borana herd sizes. But marketing patterns could matter as well since livestock sales might allow a pastoralist to smooth consumption in the wake of an adverse mortality or productivity shock, or to mitigate mortality risk by selling animals before they perish, and livestock purchases could help long-term recovery from an adverse mortality shock. Similarly, loans and gifts among households could facilitate restocking in the wake of losses. In part for these reasons, development agencies in the region are increasingly emphasizing improvements to livestock marketing infrastructure in order to increase offtake rates while also trying to reinforce traditional livestock gift and loan systems.

There is considerable anecdotal and ethnographic evidence on pastoralist livestock marketing and transfers behavior, but little published econometric work. The literature reports distress sales by the poor to the rich in times of stress, suggesting that adverse common shocks lead to increasing concentration of the aggregate herd in the hands of a few households (Watts). It also suggests that the wealthy have greater liquid, non-livestock assets and so are less likely to sell animals to resolve liquidity problems and have greater capacity to purchase animals (Kerven, Little). Our data indeed show that poorer pastoralists have a higher marketed offtake rate than wealthier pastoralists. Among those households in the lowest quartile of livestock holdings (19

or fewer head), mean offtake rate is 7.0 percent, more than double the 3.1 percent average offtake rate of the wealthiest quartile (those with 75 or more head of cattle).

The ethnographic literature describes a rich array of mechanisms that allow the transfer of animals from one herder to another (Ensminger, Little, McCabe, Schneider). One objective of these transfers seems to have been reestablishment of herds among households who suffered unexpected losses, in order that they might meet their consumption needs over time. But an equally important function of transfers seems to have been to keep people who had lost animals as mobile members of the group able to help provide for the common defense of herds and grazing areas (Huystentruyt et al.).[20] In order for a household to send a *fora* herd trekking over long distances, it must have several able-bodied males able to supervise and guard a herd and to defend themselves. Upton reports that trekkers need a minimum of two cattle or so per family member to satisfy their daily energy requirements off the herd's flow of blood and milk, generating a minimum size threshold below which herds become immobile, a point which will be important in the next section's discussion of multiple dynamic wealth equilibria. The implication for the analysis in this section, however, is that transfers may be limited to the amount necessary to restore a fellow herder's mobility and, thereby, his capacity to contribute to common defense on group treks.

The model specifications we employ to explore marketing and transfers behavior are similar in spirit to the mortality models already reported. We use two dependent variables: net sales rates as a proportion of beginning period herd size ($ns_{ijt} \equiv$ (livestock sales - livestock purchases)/ H_{ijt}), and net transfers (i.e., gifts and loans), both in levels ($NT_{ijt} \equiv$ inflows - outflows)

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[20] Indeed, historically, when covariate shocks were severe and intra-group transfers proved infeasible, households who lost their herds commonly lost their status as members of the group. For example, in neighboring Kenya, Samburu nomads who lost their animals became Dorobo hunter and gatherers, Wata hunter-gatherers absorbed former Gabra herders, and former Maasai were absorbed by neighboring cultivator groups.

and as a proportion of beginning period herd size ($nt_{ijt} \equiv NT/H_{ijt}$). In order to control for unobserved household and village factors (e.g., road improvements that increase market access, ceremonies that induce gifts from all), we estimate the following fixed-effects net sales model, with nearly the identical specification for the net transfers model:

$$
\begin{aligned}
ns_{ijt} = {} & \gamma_0 + \gamma_1 M_{ijt} + \gamma_2 M_{ijt-1} + \gamma_3 H_{ijt} + \gamma_4 H_{ijt}^2 \\
& + \sum_{r=1}^{2} \gamma_{5r} H_{ijt} R_{rjt} + \sum_{r=1}^{2} \gamma_{6r} H_{ijt}^2 R_{rjt} + \mathbf{\theta}_v \cdot \mathbf{V}_v + \mathbf{\theta}_h \cdot \mathbf{V}_h + \varepsilon_{ijt}
\end{aligned}
$$

(3)

This specification allows for testing of several hypotheses. First, the propensity for distress sales can be inferred by testing the hypothesis $\gamma_1 = 0$ in the net sales model, reflecting sales activity associated with periods of higher livestock mortality. If we reject the null in favor of the alternate hypothesis $\gamma_1 > 0$, it would seem that as pastoralists' livestock mortality increases, they sell more livestock, perhaps signaling that livestock sales represent a coping strategy for pastoralists whose asset stock is depleted and who need more liquid assets to deal with reduced livestock productivity (i.e., to purchase grain when cows are drying up). Rejecting the null in favor of $\gamma_1 < 0$ would suggest either sales reduce their mortality losses by preemptively selling off their animals or mortality supplants sales (i.e., animals die before they can be delivered to market). This also signals the potential endogeneity problem that exists if a pastoralist endogenously determines some portion of their mortality experience by opting to sell or hold their livestock. Given the data available, however, we are unable to instrument for M_{ijt} without also introducing serious multicollinearity. We therefore choose not to use instrumental variables to resolve the potential endogeneity problem.

Including lagged mortality experience (M_{ijt-1}) introduces a time dimension to distress sales and transfers. In the marketing model, a finding that $\gamma_2 < 0$ would be consistent with the expectation that herders use the market to restock after a greater-than average mortality

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experience. By contrast, a finding that $\gamma_2>0$ would suggest a vicious cycle in which herders who suffer disproportionately high mortality rates subsequently have to sell more animals in order to be able to afford to buy grain to make up the newfound milk shortages.

In the net transfers model, rejection of the null hypotheses that $\gamma_1=0$ or $\gamma_2=0$ in favor of the alternate hypotheses that $\gamma_1>0$ or $\gamma_2>0$, respectively, would indicate an inflow of animals as gifts or loans in response to relatively greater mortality losses. Such patterns suggest a social safety net based on reciprocity or solidarity motives.

The own herd size parameters, γ_3, γ_4, γ_{5r}, and γ_{6r}, signal any wealth-differentiated marketing and transfers behavior. Especially important to questions of wealth dynamics in pastoralist economies, if $\gamma_3<0$ and $\gamma_{51}>\gamma_{52}>0$ in the net sales model, wealthy pastoralists may be behaving counter-cyclically, selling more livestock during high rainfall years when demand and prices are high than when the market is saturated with distress sales during low rainfall years, at which point they buy livestock. This is the strategy that would yield the highest capital gains from livestock (Fafchamps), but we know of no empirical evidence on this conjectured behavioral pattern. As in the mortality models, own herd size enters in quadratic form to pick up any nonlinear relationships, presumably with the net sales rate decreasing in herd size, but at a decreasing rate.

The net transfers models are equivalent to the specification in (3) with one important addition. Cumulative net transfers, calculated in year t as the sum of NT from the earliest observation for the household up to year t-1, provides a simple gift/loan history for the household. If we reject the hypothesis that the effect of cumulative net transfers on NT is zero in favor of a negative relationship, it would appear that households have previously received more transfers or loans than they have given tend to be less generously treated by their neighbors than

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are those who have been net benefactors in the past. Such a finding would be consistent with the notion of social insurance based on reciprocity and would corroborate similar findings among a different population of east African pastoralists (McPeak). Unlike the mortality models' dependent variables, net transfers and sales are not censored and can be estimated using standard ordinary least squares. Including cumulative net transfers as an explanatory variable in the net transfers models, however, will bias conventional standard error estimates. We therefore report Newey-West robust standard errors in what follows.

Estimation results for the marketing and transfers models appear in Table 3. The net sales rate indeed appears to be decreasing in herd size, albeit at a decreasing rate. This corroborates past ethnographic descriptions of small herders selling proportionately more of their herds than larger herders. Rainfall appears to have no effect on marketing patterns. Rather than liquidating herds to stabilize consumption in time of drought, Boran pastoralists intentionally reduce food intake and activity levels during drought and other periods of stress in order to try to preserve herd wealth (Webb et al.), a phenomenon consistent with the asset smoothing hypothesis (Carter and Zimmerman). Nor is there any evidence of countercyclical marketing behavior so as to maximize capital gains from cattle sales. The coefficients on the contemporaneous and lagged mortality variables are very modestly positive, suggesting some possibility of distress sales, although the point estimates are statistically insignificantly different from zero.

In the net transfers models, both mortality and lagged mortality appear to positively affect net transfers, a result consistent with the existence of social insurance networks (i.e., gifts and loans). However, only the point estimate for contemporaneous mortality on net transfer rates is statistically significant at the five percent level; the other three are insignificant. Moreover, the scale of social insurance is quite modest, providing only about three animals per hundred lost this

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year, and slightly less additional transfers next year. Social insurance hardly provides a means for rapid restocking. Net transfers are modestly decreasing in beginning period herd size. The coefficient estimates on cumulative net transfers are negative and statistically significant at the one percent level, signaling that households that have consistently benefited from gifts and loans in the past are less likely to receive transfers. Combined, these results suggest the existence of a weak social insurance system among Boran pastoralists, further underscoring the importance of self-insurance through herd accumulation.

On balance, livestock marketing and transfers behavior among the Borana appears essentially nonresponsive to their mortality experience, a pattern that accords well with past findings that pastoralists seem to sell fewer livestock during tough years than would be expected if they used their herds to smooth consumption (Coppock; Fafchamps; Fafchamps et al.). Market and nonmarket exchange are not mechanisms for herd accumulation in the Borana pastoral system; natural reproduction and mortality are clearly the prime regulators of herd dynamics.

VI.   Nonconvex Wealth Dynamics and Poverty Traps

Since income depends on asset holdings, an understanding of wealth dynamics offers key insights on welfare dynamics. A burgeoning literature in both development economics and macroeconomics proffers theories and empirical tests on the existence of "low-level equilibrium" or "poverty" traps (Aziaridis and Drazen, Banerjee and Newman, Dasgupta and Ray, Loury). The core hypothesis is that there might exist multiple dynamic equilibria and thus that initial conditions matter to subsequent income or wealth accumulation trajectories. Under this hypothesis, some subpopulations find themselves "trapped" at a low, stable equilibrium, in the sense that absent a sizable positive shock to their asset holdings or incomes, their equilibrium

welfare does not grow but merely fluctuates around a penurious level. Others enjoy a higher, stable dynamic equilibrium. The hypothesis of multiple, stable dynamic equilibria necessarily implies the existence of at least one unstable dynamic equilibrium, a threshold point at which households' path dynamics switch, with households converging back to their *ex ante* dynamic equilibrium in the wake of shocks that do not push them across the threshold, but converging instead on another (lower or higher) stable, dynamic equilibrium if a shock is significant enough to push them across the threshold. The existence of multiple stable and at least one unstable dynamic equilibrium implies nonconvex wealth dynamics that are of broad importance to growth theory and empirics as well as to the economics of development. This section offers some tentative empirical findings on this topic.

Our findings on this score are tentative because of a fundamental shortcoming of our data. Recall that herd histories were collected retrospectively based on a sampling frame of pastoralists active in 1997. We have no data on households that exited the system over the period under study. Extensive, subsequent discussions with pastoralists suggests that those who have exited the system almost always had very small herds which fell victim to drought, disease or distress sale. We know of no cases of large herders "graduating" out of pastoralism. As a consequence, the attenuation bias pervasive in analyzing wealth dynamics in these data has an upward bias on period-on-period herd size changes, especially at the lower end of the wealth distribution.

The nature of herd accumulation dynamics can be addressed most simply using transition matrices depicting a household's herd size at time t and then the same household's herd size at time t+q, where q represents the interval, measured in years. We look at year-on-year transitions (q=1), five year transitions (q=5), and ten year transitions (q=10), dividing the sample into

quartiles derived by pooling all the households and years together. Quartile one includes

households with less than 19 cattle, quartile two comprises those with at least 19 but less than 34

animals, households with 34-74 head of livestock are in the third quartile, while those with 74 or

more fall into the largest quartile. The two larger boundaries almost precisely match the tercile

splits among the households with 1980/81 data, while the lower boundary coincides with the

lowest decile in the 1980/81 data. This too signals how household herd sizes have declined over

the 17 year period under study. A herd of twenty cattle put one in the lowest ten percent of these

households in 1980/81, but only in the lower 40 percent by 1997. While it is certainly possible

in the abstract that poor herders are better able to survive now than before – and can therefore be

observed today when they would have exited a generation ago – this is inconsistent with the

emergence of numerous stockless pastoralists on the Boran Plateau over the past decade.[21] The

data instead suggest to us steady degradation of average welfare among Boran pastoralists.

Table 4 shows three transition matrices, at one, five, and ten year frequencies as one

works from the top panel to the bottom. A feature that immediately jumps out is that those

households finding themselves with a small herd, one in the lowest aggregate quartile, appear

trapped. Lowest quartile herders face an almost ninety percent probability (150/171=0.88) of

remaining trapped in that quartile the next year and a slightly higher probability (36/39=0.92) of

not escaping the lowest quartile in ten years.

By contrast, those households in the upper quartile seem reasonably safe. Less than three

percent of them collapse into the bottom two quartiles the next year, and only nine percent fall

into the bottom two quartiles after ten years. Accumulating a large herd indeed appears to offer

reasonable insurance of surviving on the range. Since social insurance is modest at best, net

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[21] While a few stockless pastoralists depend on food aid and unskilled, casual labor, most appear to have
become rainfed cultivators. This has predictably fuelled cultivator-herder conflicts over grazing areas and water

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sales are largely inexplicable, and stocking rate externalities do not appear significant in these data, the Boran's propensity to attempt to maximize herd size in order to ensure survival seems well-founded.

The herd size transitions of Table 4 suggest the possibility of multiple stable dynamic equilibria, one at a low level (within the lowest quartile), and another at a higher level (within the third or fourth quartile). As discussed previously, the existence of multiple stable dynamic equilibria implies the existence of at least one unstable dynamic equilibrium, a wealth threshold at which point wealth path dynamics switch. In order to explore this possibility, we estimated the autoregression of current herd size on herd size lagged one year and ten years using a nonparametric kernel estimator.[22]

Figure 4 shows markedly nonconvex wealth dynamics, wherein there are two stable dynamic asset equilibria, one at a herd size of one – effectively, sedentarized pastoralists who have turned to cultivation while keeping a milk cow – and the other in the 40-75 head range (depending on the lag used). A threshold point appears to exist at an unstable equilibrium of 10-15 animals, which corresponds to the two-plus cattle/family member minimum herd size necessary to sustain mobile, transhumant herding, given average household size of 6-6.5 people during this period (Assefa, Coppock, Desta, Upton). Above that threshold, households can feasibly undertake the opportunistic, spatially flexible herding associated with extensive pastoralism. In the extensive pastoralism zone, wealth converges toward a larger, stable equilibrium, with herds recovering to that equilibrium in the wake of (moderate) adverse shocks

which could, in time, have adverse effects on the social organization of resource management among the Boran.
[22] We used logarithmic transforms in order to compress the domain of estimation and set ln(0)=-1 in order to retain observed periods in which households had no animals. It bears repeating that the recall data collection method induces upward bias at the lower tail of the distribution because herders who fully exited the system by 1997 were absent from the sampling frame. The precise points of the stable and unstable equilibria are thus suggestive only and less interesting than the qualitative finding of nonconvex wealth dynamics and the apparent existence of a poverty trap.

that leave them temporarily below the equilibrium, and falling toward that level due to costly increased mortality as they grow beyond the stable equilibrium herd size. When a household's stock of animals falls below the threshold level, it effectively switches to a different, sedentarized production system wherein grazing can only be done locally in order that herders can supplement insufficient own milk supplies with purchased, harvested or donated grains and other non-animal foods. Sedentarized herding is vulnerable to the region's considerable spatiotemporal variability in rainfall, however, so it becomes exceedingly difficult to maintain a herd of any size if one cannot migrate. Hence the very low stable equilibrium at one animal. It is important to note, moreover, that sedentarization with a small herd implies dire poverty in this context, as there are few nonpastoral options available to stockless, pastoralists, the vast majority of whom are illiterate (Desta, McPeak and Little).

Nonlinear wealth dynamics appear as well when one looks at variation in the observed length of time it took to recover from mortality shocks across different classes of pastoralists, defined according to the three distinct zones established by the three dynamic equilibria just discussed. As shown in Figure 4, herds smaller than 15 head after the shock fall into the sedentarization zone, converging on the low, stable equilibrium herd size. Typically, these herds will not recover from shocks, although there were a small number of cases of households completely losing their herd, in which case they should recover to the equilibrium holding of a single animal. Herds of 15 head or more post-shock, but less than 75 head pre-shock, remain within the recovery zone and would be expected to recover fully from any mortality shock. Pre-shock herds larger than the higher equilibrium of approximately 75 animals would not be expected to recover fully. They should either recover partially, to the upper, stable equilibrium,

or, if the shock sends them below the unstable equilibrium threshold of approximately 15 animals, they should not recover at all, collapsing toward the sedentarized equilibrium.

Table 5 reports on post-mortality shock spells in our sample. The rows reflect the number of years it actually took households in each class to recover to at least 95% of *ex ante* herd size after an adverse herd shock of at least 5 percent. The rightmost three columns depict recovery in the wake of relatively small shocks, just 5-15%. The central and leftmost blocks of three columns depict moderate (15 to 25%) and severe (greater than 25%) losses, respectively. The bottom two rows report the number of observations in each category and the percentage of post-shock spells in which recovery had not yet occurred by the end of our sample period. These right-censored duration data necessarily combine households that will never recover to *ex ante* herd size and households that have not yet recovered.

The results are striking and consistent with the implications of the nonconvex wealth dynamics already described. No matter the shock intensity, the largest herd sizes fail to recover within the period of the data at least 35 percent of the time, as shown in the row labeled "right censored", and recover more slowly than the other two categories. Households in the recovery zone both before and after mortality shocks and are both more likely to recover and recover more quickly than herders in either of the other two classes. Even though a 25% loss represents three or fewer animals for herd sizes below 15, only about one-third of households that fall to this point are able to recover to 95% of *ex ante* herd size within three years following the shock. These findings signal an absence of effective safety nets for Ethiopian pastoralists, in spite of recurring crises and longstanding, massive humanitarian relief efforts in the region.

VII. Conclusion

In this paper, we have exploited an uncommonly long panel of herd history data from southern Ethiopia to explore the nature of livestock mortality risk, marketing and transfer patterns, and the resulting wealth dynamics and risk management behaviors among an extremely poor population of pastoralists. Marketing and social insurance mechanisms based on reciprocity play a limited role in moderating wealth shocks. Rather, biological phenomena – calving and mortality – are the primary drivers of herd dynamics among a population that holds nearly all its wealth in the form of livestock. Part of the mortality experience is associated with covariate shocks, primarily rainfall. But household-specific asset risk dominates.

These findings have broad implications for policymakers and donors working in this area and among similarly poor populations vulnerable to climate shocks elsewhere. The existence of multiple dynamic wealth equilibria implies an important role for policy, both in keeping currently viable pastoralists from falling into poverty traps and in helping extricate those who have fallen into a low-level equilibrium trap. The importance of covariate rainfall shocks implies a regular need for external transfers into the system in times of drought, although the dominance of idiosyncratic risk suggests considerable scope for within-community mechanisms for addressing shocks through local marketing, insurance and credit systems, especially during periods of normal or near-normal rainfall.

A further practical implication for donors and policymakers working in this area and in similar environments is that the current emphasis on early warning systems to identify drought-related crises and on destocking programs to reduce overgrazing pressures on rangelands may miss the primary drivers of pastoral herd dynamics, and therefore of the welfare dynamics of pastoralists. The evidence clearly suggests that larger *ex ante* herd size is the most effective means to ensure a reasonable *ex post* herd, although beyond a stable dynamic equilibrium of 45-

75 head of cattle, large herds become unsustainable. On the other hand, once a pastoralists' herd gets too small, the household must sedentarize, becoming ensnared in a poverty trap from which it can be difficult to escape. Since we find no statistical evidence of interhousehold stocking rate externalities of the sort widely believed to exist due to "tragedy of the commons" problems, herd restocking programs for those who survive with marginally adequate herds (e.g., 15-20 cattle) appear to hold the most promise for buffering Boran pastoralists against livestock cycles due to drought and disease. For wealthier herders, asset diversification strategies that encourage offtake to 45-75 cattle – perhaps especially in response to early warning of impending drought events – may offer the most promise since mortality rates are increasing in one's herd size. A large herd ensures one's survival on the range, but the price paid in animal deaths can become quite large in herds of a hundred or more animals. Helping stimulate means for wealthier pastoralists to diversify their asset holdings may help them while also providing investable funds for non-pastoral activities (Desta).

Stimulating nonpastoral activities is important because there seem to exist multiple dynamic herd size equilibria. Small herds are not viable in extensive pastoralism. Yet sedentarized pastoralists with small herds presently lack remunerative nonfarm options. These households are trapped in extreme poverty. Assuming donors are not prepared to undertake massive restocking efforts necessary to restore the poor's mobility, restocking the poorest is largely futile and may even fuel localized range degradation around settlements (McPeak, McPeak and Barrett). Throughout history, pastoral systems have expelled their poor into settled communities, as among the Nubians along the Nile and the Palestinians along the Jordan. The best that can probably be done among the poorest pastoralists is to stimulate the availability of reasonable nonpastoral livelihood options in the rangelands through small scale cropping and

town-based employment. While the entire system has faced generalized decline of household average herd sizes, the decline in the poorest households' herds is of greatest concern in an environment where nonpastoral options remain extremely limited and, when available, offer extraordinarily low compensation (Little et al., McPeak and Little). Stimulating the nonpastoral economy in these areas while sustaining the pastoral options of the local middle class appears the most viable strategy for supporting the most destitute among an extremely risk-exposed and poor population.

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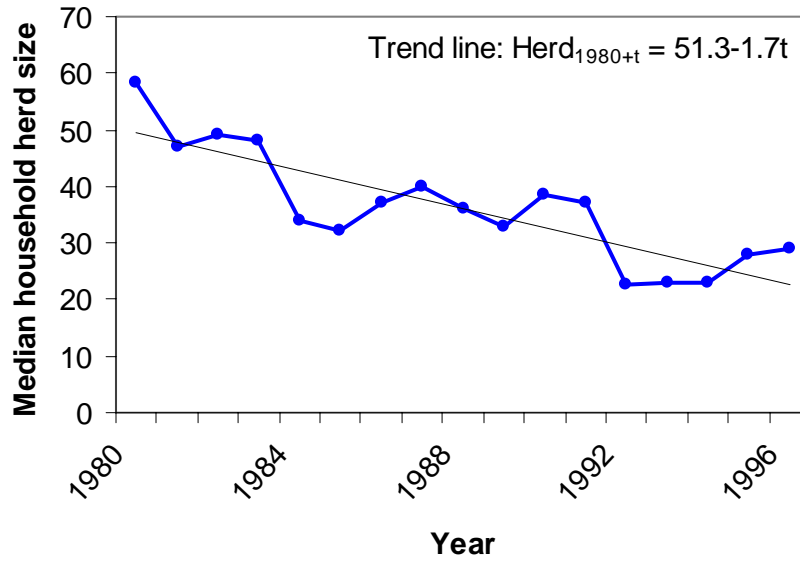
Figure 1: Cattle cycle with downward drift in median herd size

Trend line: $Herd_{1980+t} = 51.3 - 1.7t$
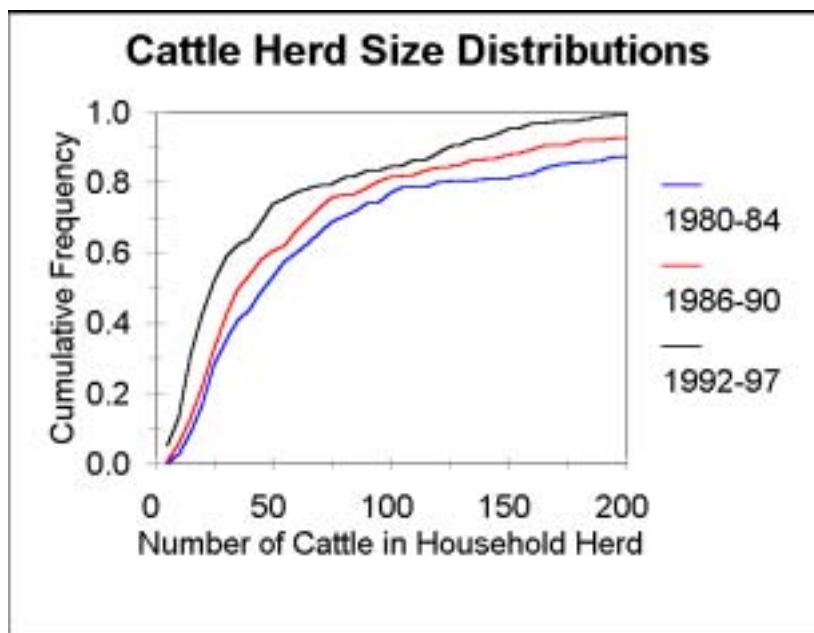
Figure 2. Household herd size-cumulative frequency

Figure 3: LOESS estimates of mortality rates, conditioned by (a) average community herd size and (b) own herd size

(a) Ln(Average community herd size)

(b) Ln(Own herd size)

Nadaraya-Watson estimates using Epanechnikov kernel with bandwidth (h=1.5)

Figure 3: Nonparametric estimates of expected herd size transition functions

Table 1. Total livestock mortality model estimates

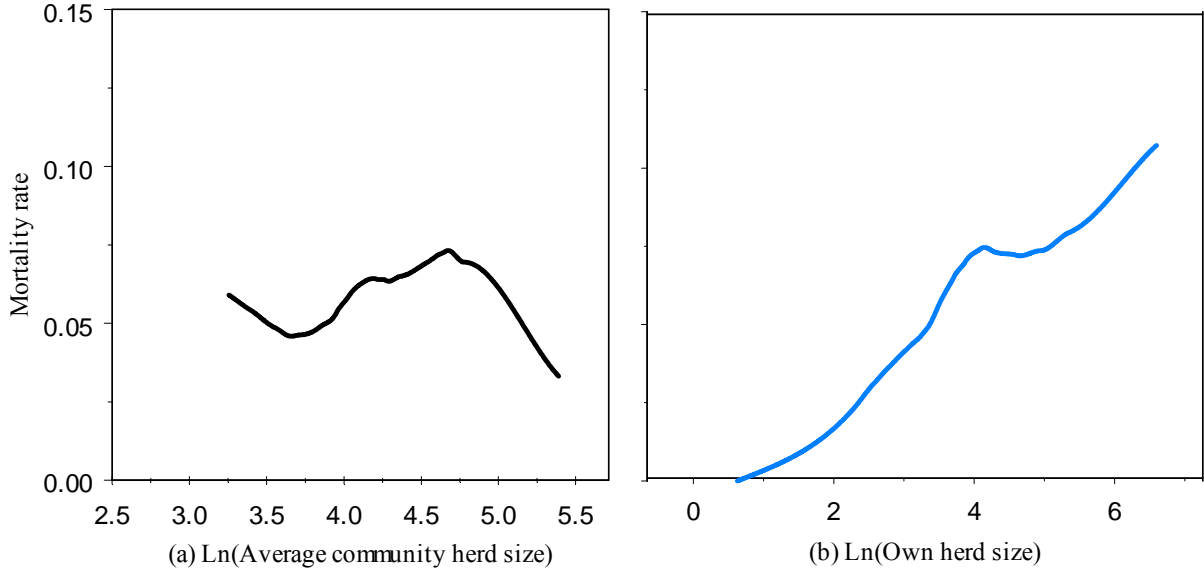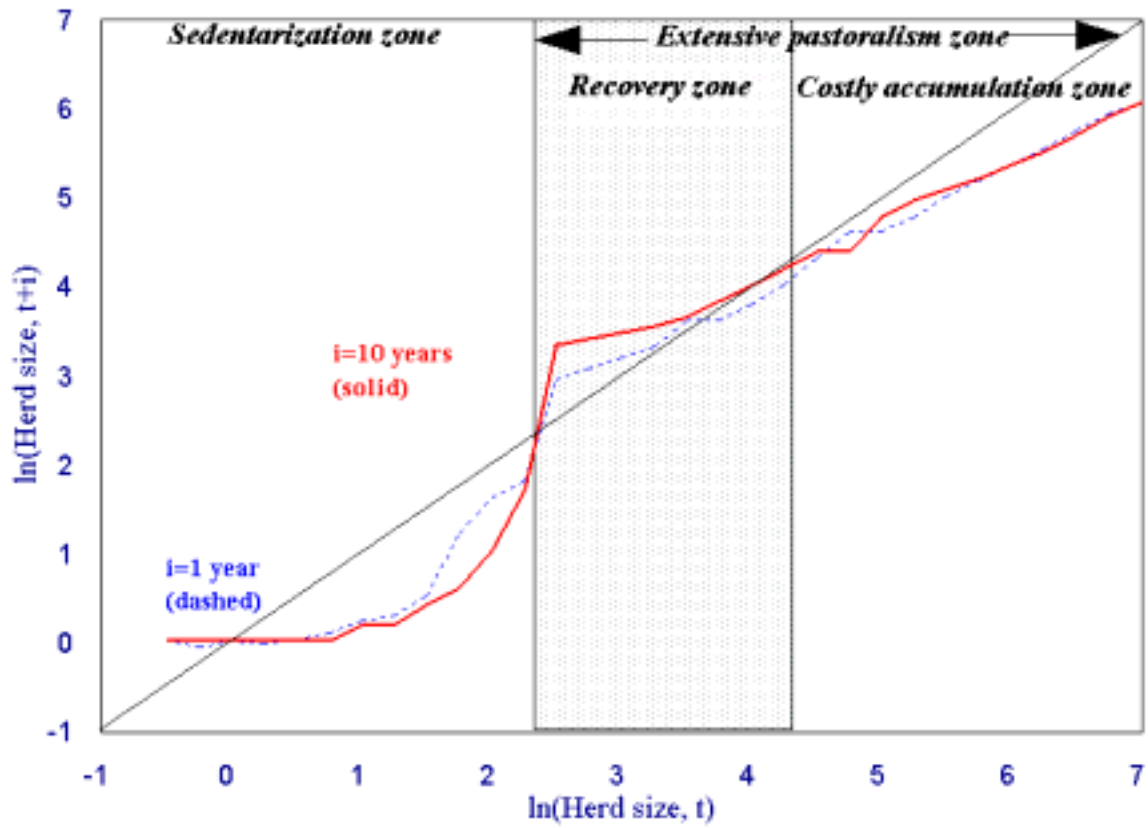| Variable	(1) Estimate		Std Error	(2) Estimate		Std Error
Intercept	-0.17	**	(0.064)	0.026		(0.075)
m_{jt}	0.55	**	(0.071)			
High Rain {0,1}				-0.25	**	(0.059)
Medium Rain {0,1}				-0.20	**	(0.062)
H_{jt}				-0.00004		(0.001)
H_{jt-1}				-0.001		(0.0004)
H_{jt} x High Rain				-0.00004		(0.001)
H_{jt} x Med Rain				-0.00016		(0.001)
H_{ijt}	0.0032	**	(0.0004)	0.0027	**	(0.0005)
H_{ijt}^2 (÷1000)	-0.0040	**	(0.0007)	-0.0032	**	(0.0008)
H_{ijt} x High Rain	-0.0017	**	(0.0004)	0.0006		(0.001)
H_{ijt} x Med Rain	-0.0012	**	(0.0004)	0.0004		(0.001)
H_{ijt}^2 x High Rain (÷1000)	0.0010		(0.0011)	-0.0031	**	(0.0014)
H_{ijt}^2 x Med Rain (÷1000)	0.0008		(0.0010)	-0.0016		(0.0012)
Yabello {0,1}	0.045		(0.078)	0.073		(0.081)
Mega {0,1}	-0.18	*	(0.090)	-0.14		(0.093)
Arero {0,1}	-0.075		(0.084)	-0.093		(0.086)
Number of Observations	834			834		
Noncensored Values	494			494		
Right Censored Values	2			2		
Left Censored Values	338			338		
Log Likelihood	-183.11			-185.30		

* (**) indicates statistical significance at the 10% (1%) level

Table 2. Calf mortality model estimates

Variable	(1) Estimate		(1) Std Error	(2) Estimate		(2) Std Error
Intercept	-0.14	**	(0.038)	-0.071		(0.043)
m_{jt}	0.53	**	(0.123)			
High Rain {0,1}				-0.088	**	(0.034)
Medium Rain {0,1}				-0.062	*	(0.035)
H_{jt}				0.0002		(0.0003)
H_{jt-1}				-0.0002		(0.0002)
H_{jt} x High Rain				-0.0001		(0.0004)
H_{jt} x Med Rain				-0.0003		(0.0004)
H_{ijt}	0.002	**	(0.0002)	0.001	**	(0.0003)
H_{ijt}^2 (÷1000)	-0.002	**	(0.0004)	-0.002	**	(0.0004)
H_{ijt} x High Rain	-0.001	**	(0.0002)	-0.0001		(0.0004)
H_{ijt} x Med Rain	-0.0005	*	(0.0002)	0.0002		(0.0003)
H_{ijt}^2 x High Rain (÷1000)	0.0014	*	(0.0006)	-0.0004		(0.0008)
H_{ijt}^2 x Med Rain (÷1000)	0.0004		(0.0005)	-0.0007		(0.0007)
Yabello {0,1}	0.047		(0.046)	0.057		(0.047)
Mega {0,1}	-0.027		(0.051)	-0.012		(0.052)
Arero {0,1}	0.009		(0.048)	0.009		(0.049)
Number of Observations	834			834		
Noncensored Values	374			374		
Right Censored Values	0			0		
Left Censored Values	460			460		
Log Likelihood	25.37			29.08		

* (**) indicates statistical significance at the 10% (1%) level

Table 3. Livestock marketing and transfers estimates (with robust standard errors)

Variable	Net Livestock Sales ns_{ijt}		Net Livestock Transfers NT_{ijt}		nt_{ijt}	
	Estimate	Std Error	Estimate	Std Error	Estimate	Std Error
Intercept	0.063 **	(0.022)	1.37	(1.092)	0.077 **	(0.025)
M_{ijt} (÷100)	0.016	(0.018)	2.99	(2.120)	0.046 *	(0.027)
M_{ijt-1} (÷100)	0.016	(0.0100)	2.43	(1.841)	0.014	(0.0121)
H_{ijt} (÷1000)	-0.065 **	(0.019)	-0.515	(1.962)	-0.111 **	(0.040)
H_{ijt}^2 (÷1000)	0.0009 **	(0.0003)	-0.021	(0.047)	0.0011 *	(0.0005)
H_{ijt} x High Rain (÷100)	-0.0056	(0.015)	-2.01	(1.550)	-0.029 *	(0.016)
H_{ijt} x Med Rain (÷100)	-0.014	(0.014)	-3.45 *	(1.351)	-0.033 *	(0.017)
H_{ijt}^2 x High Rain (÷1000)	0.0004	(0.0004)	0.084 *	(0.048)	0.0011 *	(0.0005)
H_{ijt}^2 x Med Rain (÷1000)	0.0005	(0.0004)	0.148 **	(0.056)	0.0010 **	(0.0004)
Cumulative NT_{ijt}			-0.088 **	(0.028)	-0.0013 **	(0.0005)
Yabello {0,1}	-0.022	(0.028)	8.49 *	(3.849)	0.222 *	(0.093)
Mega {0,1}	0.063 *	(0.032)	-2.56	(2.421)	0.075 *	(0.035)
Arero {0,1}	0.034	(0.030)	4.44 *	(1.797)	0.107 **	(0.031)
R^2	0.161		0.221		0.100	

* (**) indicates statistical significance at the 10% (1%) level

Table 4. Cattle herd size transition matrices (count of household-year pairs)

			Period t+1			
				Quantile		
			1	2	3	4
Period t	Quantile	1	150	21	0	0
		2	28	137	25	0
		3	5	23	136	19
		4	1	4	13	162

			Period t+5			
				Quantile		
			1	2	3	4
Period t	Quantile	1	70	11	4	0
		2	48	65	24	2
		3	22	37	63	21
		4	2	4	30	104

			Period t+10			
				Quantile		
			1	2	3	4
Period t	Quantile	1	36	3	0	0
		2	25	28	12	1
		3	22	17	29	9
		4	5	1	14	50

Table 5. Herd recovery rates in the wake of adverse shocks

Herd Size:	<15 *ex post*	>15 *ex post*		<15 *ex post*	>15 *ex post*		<15 *ex post*	>15 *ex post*	
		<75 *ex ante*	>75 *ex ante*		<75 *ex ante*	>75 *ex ante*		<75 *ex ante*	>75 *ex ante*
Years until	**Shock Intensity**								
95% recovery	**>25% loss**			**15-25% loss**			**5-15% loss**		
1	5.9%	17.4%	8.3%	23.1%	46.6%	15.4%	47.1%	58.3%	31.5%
2	5.9%	17.4%	8.3%	11.5%	13.8%	11.5%	14.7%	13.5%	16.7%
3	23.5%	13.0%	8.3%	19.2%	6.9%	15.4%	5.9%	8.3%	7.4%
4	5.9%	13.0%	0.0%	7.7%	6.9%	7.7%	5.9%	4.2%	3.7%
5	0.0%	4.3%	16.7%	0.0%	5.2%	3.8%	5.9%	5.2%	3.7%
6	0.0%	0.0%	0.0%	3.8%	1.7%	0.0%	2.9%	3.1%	0.0%
7	0.0%	4.3%	8.3%	0.0%	0.0%	0.0%	0.0%	0.0%	1.9%
8	17.6%	4.3%	0.0%	0.0%	3.4%	0.0%	0.0%	0.0%	0.0%
9	0.0%	4.3%	0.0%	0.0%	1.7%	0.0%	0.0%	0.0%	0.0%
10	0.0%	0.0%	8.3%	3.8%	0.0%	3.8%	0.0%	0.0%	0.0%
% right censored	41.2%	21.7%	41.7%	30.8%	13.8%	42.3%	17.6%	7.3%	35.2%
n	17	23	12	26	58	26	34	96	54