# Traps and Thresholds in Pastoralist Mobility[1][2]

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**Abstract**

Thresholds in asset accumulation dynamics can drive a wedge between households able to pursue relatively high-return, asset-based economic activities and those forced into lower return alternatives. While some evidence has been found for such thresholds amongst pastoralist communities in the arid and semi-arid rangelands of northern Kenya, relatively less is known about the mechanisms behind such poverty trap phenomena. The setting is particularly suitable for such a study because there is one primary high-return livelihood, mobile pastoralism, based on a scalar primary asset stock, livestock. Sustainable pastoralism involves livestock movements in response to the bimodal rainfall distribution. I develop and provide empirical tests for the implications of a simple model capturing the idea that the bifurcation in asset dynamics is driven by a threshold in the incentive to engage in mobile pastoralism. Additional evidence is presented regarding pastoralist movement patterns. Data collected on pastoralist concerns allows us to look at the effect of subjective beliefs on subsequent mobility and movement behavior.

# 1 Introduction

The question of whether individuals or households can end of up structurally trapped in poverty is central to our understanding of poverty and what to do about it. If people find themselves in such traps they can dictate welfare dynamics, which can persist into the future if households are mired in a low-returns trap that prevents investing in the future, including through education. If people can find themselves mired in structural poverty due primarily to historical reasons or bad luck, this provides strong justification for policies meant to move people out of such traps, and to provide buffers against others falling in. A strand of the theoretical literature suggests the possibility of such traps. The general approach is to posit a key input or asset that is critical for individual productivity, such a nutrition (Dasgupta and Ray, 1986), human capital (Azariadis and Drazen, 1990; Galor and Zeira, 1993), or physical capital (Banerjee and Newman, 1993), and provide a mechanism, such as borrowing constraints or externalities, that leads to a significant number of individuals having a suboptimally low allocation of the key input.

The growing empirical literature that has emerged to test for poverty traps, often based on trying to find a non-linearity in household income, expenditure, or asset dynamics through various techniques and data configurations, has found mixed results. One setting in which we find quite robust evidence for asset poverty traps is in the pastoral rangelands of east Africa, in which empirical inference is simplified because there is a singular, higher-return, asset-based livelihood, mobile pastoralism (Lybbert et al., 2004; Barrett et al., 2006). Far less evidence, however, exists on the particular *mechanisms* that might drive non-linearities in asset dynamics, which is needed to better characterize such thresholds, and critical for policy design in response to apparent poverty traps. Little et al. (2008) suggest that the bifurcation in asset dynamics is due to the nature of mobile pastoralism, which is the primary risk-management tool employed by pastoralists in response to variable rainfall conditions. This potential break point in long-run incentives to engage in active asset accumulation corresponds to the 'Micawber threshold' in this setting (Zimmerman and Carter, 2003; Carter and Barrett, 2006).[1] In this paper I build on evidence of non-linear asset dynamics in the pastoral rangelands of northern Kenya, specifying and testing a model capturing the idea that a bifurcation in asset accumulation dynamics is driven by the opportunity costs and incentives resulting from the mobile pastoralism livelihood in comparison to the sedentary alternative.

In Kenya alone, government statistics indicate that pastoral areas occupy at least 80 percent of the land mass, home to about 10 million people and 90 percent of the country's wildlife (Irinnews, 2007). It is crucial to understand how the sustainability of the mobile pastoralism livelihood can

[1] Poverty rates in this population are much higher amongst those who have "fallen out" and don't have the option of engaging in mobile pastoralism (Little et al., 2008).

be maintained in the face of current challenges, including climate change, security risks, increased competition for scarce land, water and other resources, and shifting prices for animal-based products. Poverty rates are much higher amongst those who have "fallen out" and don't have the option of engaging in mobile pastoralism (Little et al., 2008). A key question is whether those who have moved out of mobile pastoralism have fallen into a structural poverty trap, and what mechanisms might be driving such state. In addition, it is important to understand movement and herd accumulation choices. Pastoralist grazing patterns have caused tremendous environmental degradation in the region, including spurring on desertification (McPeak, 2003), while herd mobility can lead to violent inter-tribal conflict, given that property rights over waterpoints and grazing lands are not clearly delineated between rival tribes.

While most papers modeling non-convexities in asset dynamics make use of some kind of fixed, indivisible cost of *entering* the asset-intensive, higher-return livelihood (which the individual is constrained from meeting, perhaps due to credit market failures), the posited mechanism here is slightly different. Instead of an entry cost, I hypothesize three context-specific factors. First, mobile pastoralism requires a significant commitment of resources, as sufficient household herding labor must be committed during biannual dry seasons, which last 2-4 months. In practice, presumably due to weak contracting frictions and social norms, households take responsibility for their own herds, setting up remote 'satellite camps' for the mobile herd, leaving behind sufficient lactating herd resources in the village to provide consumption for female, transhumant and very young members of household. Hence household labor is pulled away from remunerative activities in the central town, however limited they are,[2] and dedicated exclusively to animal herding for a significant portion of the year. Clearly for a minimal level of village earnings possibilities, there will be a minimal herd size necessary for mobile pastoralism to be optimal. Second, herd growth rates differ between mobile pastoralism, which generally exposes animals to higher-quality forage resources (in spite of increased activity from movement) and sedentarism, and biology dictates that herd growth by reproduction is difficult at low herd sizes. This again points to low returns to mobile pastoralism at small herd sizes. Finally, such poor households in a location with shaky social protections face a prominent subsistence consumption threshold, and risk concerns only intensify the preference of households for a more certain stream of returns. These factors together can generate a bifurcation in the incentive to engage in mobile pastoralism. Notice that the lack of credit markets can still be important here– households could in principle borrow a large enough sum of money in order to move their herd size significantly beyond the threshold. Yet it is still the case that the poverty is not driven directly by a large, fixed cost of entry into the higher-return livelihood.

[2] Sedentarisation 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, 1999; McPeak and Little, 2004).

The primary tool employed for the identification of a bifurcation in incentives to pursue mobile pastoralism is a semiparametric panel estimator, implemented through cubic splines, that allows for a flexible specification of the relationship between (labor-adjusted) herd size and a household's propensity to pursue mobile pastoralism.[3] The empirical model is based on a generalized additive model framework, which has the advantage of allowing the analyst to additionally control for observable heterogeneity amongst herder households through linear covariates, and for unobservable heterogeneity through fixed or random effects. Analogous techniques have been employed by Naschold (2008) to attempt to flexibly identify bifurcation thresholds in asset accumulation dynamics while simultaneously controlling for linear covariates. I provide a number of additional sources of evidence on the threshold result, and a number of robustness checks. In addition, some more recent work in this area has moved beyond the identification of thresholds averaged across the population, into exploring the role of heterogeneity in asset dynamics and livelihood options. Santos and Barrett (2006), exploiting data on pastoral livelihoods in southern Ethiopia, extract a measure of ability in pastoralism, and show that asset dynamics can vary greatly in ability. Following Santos and Barrett (2006) I extract a measure of pastoral ability based on observed herd growth performance, and incorporate this additional measure into the threshold analysis. This provides evidence on a potential tradeoff in mobility between herd size and underlying ability. The move from one to two-dimensions also provides a simple demonstration of how such semiparametric techniques might be useful in study potential poverty trap phenomena in settings where the asset vector is naturally higher-dimensional.

In addition to directly looking at the relationship between herd size per capita and mobility status, I study the influence of other factors on mobility patterns. This includes characteristics of the household and household head, such as age, education, and household labor structure. In addition, data collected on concerns of herders about future events such as lack of water resources or conflict allow me to provide evidence on the influence of subjective beliefs on mobility and movement patterns. I then provide additional evidence on household *movement* patterns, using mobility as a selection condition to identify the set of mobile households. I look at frequency of herd movements, two measures of time spent at remote waterpoints, and maximum distance moved, as dependent variables.

[3] It is natural in the empirical analysis to model the propensity to engage in mobile pastoralism as the dependent variable, and herd size as an explanatory variable, as in the short-run herd size is roughly fixed, while mobility is a free choice. However, in the long-run the causality switches–the decision to engage in mobile pastoralism determines the evolution of the herd stock. This implies that an estimated threshold in asset dynamics is probably biased downwards, and so for example for policy implications in an area like herd-stocking, we should probably take the threshold estimate as an absolute lower bound.

## 1.1 S-Shaped Asset Accumulation Dynamics and Poverty Traps in East African Pastoralism

Lybbert et al. (2004) and Barrett et al. (2006) use a nonparametric kernel approach to identify S-shaped asset accumulation dynamics, using data from pastoralists in southern Ethiopia, and rural Kenya (covering two common research sites with this paper), respectively. Their results provide important motivation for the application in this paper, by pointing to a bifurcation in asset accumulation dynamics in rural pastoralism. The graphs give a measure of household herd size in a fixed period on the $x$-axis, and the subsequent value of the measure in the next period. In both figures the animal stock is indexed in terms of tropical livestock units (TLU),[4] while in the latter figure herd size is normalized by a measure of household size (I also adopt the per capita measure of herd size). The points where the graphs cross the 45-degree line with a slope greater than the 45-degree line indicate unstable dynamic asset equilibria, while those with slope less than the 45-degree line indicate stable dynamic asset equilibria. Values of the graph below the 45-degree line are decumulation zones: on average, herder assets should be decreasing within these zones. Values above the 45-degree line correspond to accumulation zones.

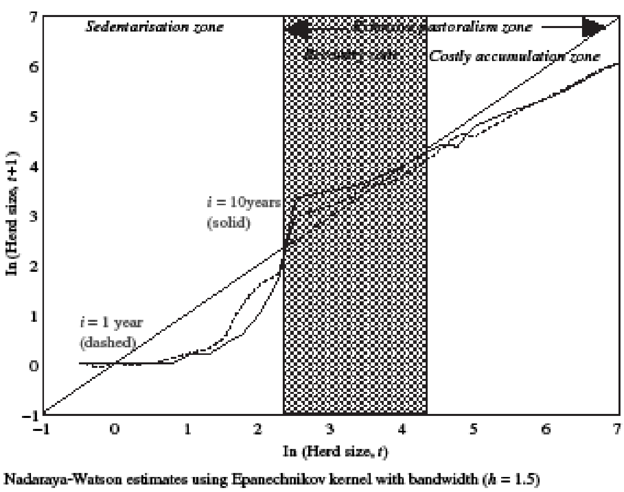



Figure 1. Herd dynamics Lybbert et al. (2004).

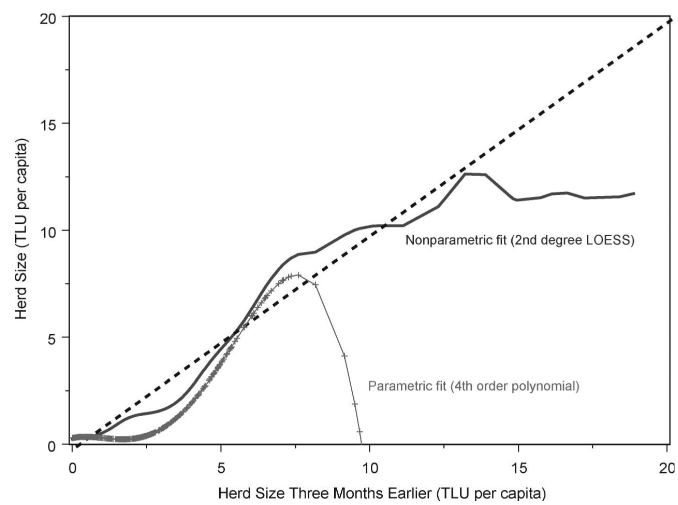



Figure 2. Herd dynamics Barrett et al. (2006).

The graph in Figure 1 is particularly useful, as it presents the (expected) asset accumulation regimes explicitly. In such a growth diagram we see where the asset accumulation threshold exists,

[4] TLU is the standard livestock asset index in the literature, where 1 TLU = 1 cow = 0.7 camels = 10 sheep or goats.

at around 2.2 (in log terms; that is, about exp(2.2) = 9.03 TLU). Above the threshold herders are expected to increase their herd stock back to a more sustainable threshold, here around 4.2 (in log terms; exp(4.2) = 66.69), while below they are expected to converge to the low-level sedentary activity, which here is around 1 TLU. Hence both diagrams seem to be indicative of critical thresholds in asset accumulation dynamics. Finally, the figure from Barrett et al. (2006)

With this context, then, the key research question here can be stated as: what are the mechanisms driving the bifurcation in asset accumulation dynamics in terms of livelihood patterns?

The paper proceeds as follows. Section 2 presents a model of pastoralist mobility and herd asset accumulation choices, which frames the research hypotheses, including the threshold effects in mobility. Section 3 outlines the empirical strategies employed in the paper. Section 4 describes the data. Section 5 presents results and robustness checks, and Section 7 concludes. Supplementary material is presented in the Appendices A-C.

# 2 A Model of Pastoralist Choice Over Mobility and Herd Asset Accumulation

The empirical analysis in this paper is based on the mobility and movement choices of individual pastoralist households. In this section I outline a relatively simple model that illustrates the salient aspects of the choice problem of an individual household, from which I derive the primary empirical hypotheses that will be tested in later sections. In the model each household faces the discrete choice between engaging in mobile pastoralism or the alternative, sedentary livelihood. The vast majority of households engaged in mobile pastoralism in the dataset are not nomadic but rather migratory–a central base camp is maintained year-around, which will permanently include female, transhumant and very young members of household. During the dry season, male household members, older children and teenagers form the labor force that tends to the herd in the field, called the "satellite camp", moving the herd between remote waterpoints; hence the model includes a simplified version of the waterpoint movement choice. A relatively small portion of the lactating subherd is left at the base camp, which can provide sustenance to the family members staying behind.

The model captures a potential non-convexity in the returns envelope of the household, which is driven by the discrete choice between a stochastic, higher expected return herd growth technology, and a lower-return, but (for simplicity) deterministic herd growth technology. While non-convexities in returns are often specified as a fixed cost or some other generic specification, here I focus on three micro-mechanisms that might drive the threshold: (1) labor earnings available from sedentarism (which are not available to a household committed to mobile pastoralism, so that such labor earnings are a (fixed) opportunity cost of mobile pastoralism), (2) a subsistence consumption threshold, and (3) differential herd-growth returns from each herd growth technology, due both to non-linear herd growth through reproduction and differences in herd viability obtaining from mobile pastoralism versus sedentarism.

At the beginning of a period the household makes a decision about whether to engage in mobile pastoralism, denoted by $M$ in what follows, or alternative remunerative activities (e.g., petty trading or wage labor in the town), denoted by $A$. The household begins the period with two key assets. First, the livestock herd, containing $Z$ units of livestock, is normalized by a scalar index for available household labor, $l$, in order to be converted into a scalar index denoted by $Z/l = z \geq 0$, which is units of livestock per unit of household labor. Second, an immutable ability level, $a$, which for simplicity fully captures *relative* ability in herding.

At the beginning of each period the household faces a choice over adopting the stochastic herd-growth technology from engaging in mobile pastoralism, $g_M(z, a, l)\,\epsilon_w = z'$, $w \in W$, which maps herd assets at the beginning of the period, $z$, into herd assets at the end of the period, $z'$, subject to the household's ability and labor supply and a mean-one random shock with strictly positive support, $\epsilon_w$, where $w$ represents a waterpoint in the set $W$ of waterpoints that the household can choose to migrate to. The choice of $M$ represents a commitment on the part of the household to engage in mobile pastoralism, including dedicating the available household labor to this task, and it is this commitment which generates the flow benefits. The alternative is the herd growth technology $g_A(z) = z'$, a non-stochastic growth function based on sedentarism. I omit ability and household labor from this function by assuming that management of the sedentary herd has few ability or labor requirements.

I make the following assumptions. First, $g$ is continuously differentiable, with $\partial g_i/\partial z > 0$, $\partial g_M/\partial a, \partial g_M/\partial l > 0$, and $g_M(0, a, l)\,\epsilon = 0$ for any $a$, $g_A(0) = 0$–the next-period herd is greater given greater ability and starting herd size, and regardless of ability, households cannot create a herd from nothing. Second, in practice the pastoralist household faces significant uncertainty over movement choice, including over rangeland features like rainfall and forage, and the likelihood of experiencing raids or conflict. Hence I use the expectation operator $E$ to capture subjective expectations over the distribution of $\epsilon_w$. Finally, indexation by mobility choice ($M$ or $A$) captures the idea that herd growth varies according to whether or not the household engages in mobile pastoralism. As discussed in McPeak and Barrett (2001), herd productivity can be depressed under sedentary pastoralism, as forage resources suffer from long-term degradation near the villages, and water access can be constrained during dry seasons. This is only reinforced by more recent work suggesting negative net herd accumulation below a critical asset threshold (e.g., Lybbert et al., 2004; Barrett et al., 2006). Hence it is reasonable to assume that if $z > 0$, $Eg_M(z, a, l)\,\epsilon = g_M(z, a, l) > z > g_A(z)$, for all $l > 0$

and $a$. Namely, positive herd growth is expected for technology $g_M$, negative herd growth obtains for $g_A$, and hence at any positive herd size, herd growth is expected to be greater from technology $g_M$. This generates a bifurcation of herd dynamics around the critical switching threshold between $M$ and $A$.

Mobile pastoralism carries with it an opportunity cost, as it involves a commitment of household labor resources. I model the earnings that can be obtained from choosing a sedentary livelihood by $e(l) \in [0, \bar{e}]$, which for simplicity I take to be a deterministic function of the index of household labor supply. The upper bound on returns, $\bar{e}$, captures that idea that earnings opportunities are limited in a poor, rural setting. For notational simplicity, I take $e$ to be realized in livestock units . The household can then potentially generate consumption from two sources: benefits taken from the herd, and alternative sedentary earnings. I use $r_i(\cdot)$, $i = A, M$, to denote a return function that translates the flow benefits from the herd asset (e.g., harvesting milk or blood) into the same herd-unit return scale as $e(l)$,[5] and assume $r_i \geq 0$, $r_i(0) = 0$ and $r_i'(z) > 0$. In order to avoid modeling herd management choices of the household, since they are not considered in the empirical analysis, I assume that all of the benefits from the herd are flow benefits. Hence the benefits from herding are as follows. Mobile pastoralism generates the expected flow payoff $E[r(g_M(z,a,l)\epsilon)]$, with the expected net gain in herd size $(Eg_M(z,a,l)\epsilon - z)$, while the sedentary alternative generates net flow payoff $[r(g_A(z))] + e(l)$, with net gain in herd size $(g_A(z) - z)$.

I assume that the household evaluates returns in herd units according to a utility function $U$. I assume that the household faces a minimal subsistence consumption constraint, $\underline{c}(l) > 0$, and that $U$ "kinks" at $\underline{c}$: $U$ is strictly increasing, differentiable, and strictly concave above $\underline{c}$, while below $\underline{c}$ its slope is constant (for simplicity), and sharply steeper.[6] This reflects the idea of a very strong disutility from obtaining a consumption level below $\underline{c}$. Rather than introducing additional complication through a "soft" subsistence constraint, I instead simply assume that $e(l) \geq \underline{c}$ – the household can satisfy its bare minimum consumption needs by remaining sedentary (this may include taking advantage of food aid, or depending on support from other family members, for example, in addition to village-based employment opportunities). In order to capture potential dynamic considerations in choice, I also include the term $\Psi(z,a,l)$, strictly increasing in both arguments, which is meant to capture potential future returns from herd assets, ability, and labor supply, and hence generates an end-of-period tradeoff in the allocation of herd assets to consumption. In particular, it

[5] This is for simplicity, under the assumption that flow benefits from the herd can be realized at their marginal benefit to the household, and all consumption goods are freely available, without additional market transaction costs. In fact, households are the suppliers of much of their own consumption through milking, etc., in this setting, but incorporating this subtlety only complicates the modeling.

[6] Formally, let $U$ be continuous at $\underline{c}$: $\lim_{x\uparrow\underline{c}} U(x) = \lim_{x\downarrow\underline{c}} U(x)$; however, $\lim_{x\uparrow\underline{c}} U'(x) < \beta$, where $\beta = U'(x)$ for any $x \in [0, \underline{c}]$.

captures the idea that a pastoralist household might choose to sacrifice consumption today in order to preserve the long-run asset stock, which has been called "asset smoothing" (Carter and Barrett 2006; Barrett et al. (2006) provide some evidence for such behavior amongst northern Kenyan pastoralists.).

The pastoralist household's beginning of period value function is given as follows,

$$
\begin{aligned}
V(z,a,l) = \max\{&\max_{w\in W} E\left[U\left(r_M\left(g_M(z,a,l)\,\epsilon_w\right)\right) + \Psi\left(g_M(z,a,l)\,\epsilon_w, a, l\right)\right], \\
&\left[U\left(r_A\left(g_A(z)\right) + e(l)\right) + \Psi\left(g_A(z), a, l\right)\right]\} \\
\text{s.t. } & r_M\left(g_M(z,a,l)\,\epsilon_w\right) \geq \underline{c}(l),
\end{aligned}
$$

where the condition $r_M\left(g_M(z,a,l)\,\epsilon_w\right) \geq \underline{c}(l)$ only needs to hold if $M$ is chosen.

## 2.1 Hypotheses: Theoretical Predictions

The basic model above guides us to some implications for herd mobility. The first Claim concerns the selection conditions between mobile pastoralism and sedentarism, as a function of herd size per capita and ability.

**Claim 1** *There is a threshold function $f(z,a)$, which characterizes the boundary of indifference between livelihoods $M$ and $A$ for a given value of $l$, where for lower values of $z, a$ the household is more likely to engage in $A$; hence $f$ identifies the Micawber threshold. In addition, for fixed values of $a$ and $l > 0$, there are threshold values of $z$, $\bar{z}$ and $\underline{z}$, where for $z > \bar{z}$ the household always engages in $M$, and for $z < \underline{z}$ the household always engages in $A$.*

To derive the second claim just regarding $e$, notice that for $z = 0$ returns to herding are deterministically set to zero. With $l > 0$, sedentarism always generates some strictly positive return. Meanwhile, as long as $l > 0$, with $e$ bounded by $\bar{e}$, since the herd growth function is strictly increasing in $z$ and $\epsilon$ has strictly positive support, as $z \to \infty$ the expected returns to herding are unbounded. Since the expected returns to $z$ are monotonic in $z$, it follows directly that in the range $z \in [0, \underline{z}]$ the household always engages in sedentarism, there is a range $(\underline{z}, \bar{z})$ in which the household's choice will depend on its particular risk preferences and other characteristics, while for $z \in [\bar{z}, \infty)$ the household will always engage in mobile pastoralism.

**Claim 2** *Because $\psi$ dictates a consideration of future outcomes, one might pursue mobile pastoralism in the present period even if it means lower expected payoff in the present.*

The result is trivial given that $\psi$ is increasing in $z$. What it tells us is that, due to risk, the induced mobility threshold may be lower than the maximization of static returns would dictate.

That is, households near (but below) the switching threshold may be induced to engage in mobile pastoralism, in order to enjoy the increased herd growth (and a potential positive herd growth shock) in order to leap above the threshold, rather than resigning itself to sedentarism. This implies that we should be cautious in interpreting the herd-size threshold in the empirical work–it probably represents an absolute lower bound on the static-optimal herd size needed for mobile pastoralism, and hence policies designed to support mobile pastoralism (such as herd-restocking) should probably work with a larger threshold.

**Claim 3** *The effects of household labor, $l$, on outcomes are ambiguous. In particular, the expected returns to mobile herding are increasing in labor only where*

$$g_{M,l}(z,a,l) > \frac{z}{l} g_{M,z}(z,a,l).$$

The model generates a tradeoff in the returns to labor. On the one hand, household labor normalizes the herd stock index, $z = Z/l$, so that increased household labor implies less mobility and lower herd growth as per capita herd resources decrease. On the other hand, an increase in labor implies greater herd growth as $l$ appears positively in the herd growth function for mobile pastoralism. Hence within mobile pastoralism, the above condition is derived as,

$$\begin{aligned} \frac{d}{dl}\left[E g_M(z,a,l)\,\epsilon_w\right] &= \frac{d}{dl}\left[g_M\left(\frac{Z}{l},a,l\right)\right] \\ &= -\frac{z}{l} g_{M,z}(z,a,l) + g_{M,l}(z,a,l). \end{aligned}$$

This leaves the effect of labor on mobility ambiguous in general. However, all things equal, given that the term $z/l$ appears in the expression, this suggests that at higher levels of total labor the household should be more likely to be mobile.

Greater household labor also generates greater returns from sedentarism, as more household members are available to seek sedentary earnings. At a very low herd size, where households might also be expected to be more sensitive to risk, we can expect that the opportunity cost of herding is too high, particularly for a larger household, and hence sedentarism becomes increasingly likely. As herd size increases, we expect the propensity to engage in mobile pastoralism to increase. A trivial extension to the model would be to capture the effect that as herd size becomes large the household might be more likely to diversify its returns portfolio, engaging in some town-based business activity in addition to herding.

The following Claims concerns the household's response to uncertainty.

**Claim 4** *All things equal, if the household puts greater subjective probability weight on adverse out-*

*comes from mobile pastoralism, it is less likely to engage in mobile pastoralism.*

This result is unsurprising; formally, as the expectation operator $E$ assigns greater weight to adverse events (low-$\epsilon$ shocks), then the household's expected returns to mobile pastoralism are lower, and hence the household is less likely to engage in mobile pastoralism.

**Claim 5** *All things equal conditional on mobility, regarding movement choice over the menu of waterpoints, the household will select waterpoints that best meet the household's desire to minimize risk.*

The model captures the movement choice over $w \in W$. Each household has beliefs over the returns distribution at each waterpoint, which is capturing real-world factors such as conflict or raid potential, and riskiness of water and forage access. Of course, the returns to waterpoints also depend on the presence or absence of other herders in that location; I abstract away from this particular factor, just considering incentives emanating from household and waterpoint characteristics. I conjecture that greater concerns over waterpoint return factors should direct the household to be more likely to identify a given waterpoint to locate at, and hence a lower number of movements, a larger maximum distance moved, a increased time spent at a given waterpoint. Although this is not captured in the model, I also conjecture that a household with a larger herd, all things equal, should spent greater time at a given waterpoint, due the increased risk of moving a large herd, and the social power that larger herds bring.

The last claim will not be tested in the empirics herein; however, the result is useful to verify relative to existing literature.

**Claim 6** *The subsistence consumption constraint, along with the assumptions that $Eg_M(z, a, l, \epsilon) > g_A(z)$ for all $z > 0$, $l > 0$ and $a$, $g_M(0, a, l, \epsilon) = 0$ for any $a$, $g_A(0) = 0$, and $e(l) \geq \underline{c} > 0$ capture the idea that the presence of risk might induce underinvestment in productive assets (Rosenzweig and Binswanger, 1993; Carter and Barrett, 2006). The risk-averse poor may prefer to select the low-risk asset portfolio, which guarantees the return to meet subsistence consumption, $\underline{c}$, in the short run, but which carries lower expected returns in the long-run.*

# 3 Empirical Strategy

## 3.1 Operationalizing Mobility

Here I outline the empirical strategy to identify latent mobility, to identify the bifurcation in the choice of livelihood technology between mobile pastoralism and the sedentary subsistence livelihood. I begin by defining mobility in this context.

**Definition.** *A given herder household is mobile if it is viable to move a portion of their herd to a waterpoint outside of the one-day movement radius of the central town they are associated with in a given time period.*

This definition implies that a household is mobile if it has the necessary resources in order to engage in full-time pastoralism during time periods in which this is necessary (dry or drought periods), being able to commit household labor to moving livestock which precludes that labor from engaging in other remunerative activities. The one-day movement radius of the village defines the boundary between the water resources which are just sufficient for those remaining in the village during a given season, and those outside. In order for mobility to be viable, it has to overcome the opportunity costs of herding (which partly includes the calculation of the expected returns from maintaining a given herd stock), and that they meet a minimum subsistence consumption threshold.

The empirical study of mobility involves a latent variable problem (i.e., whether or not a household is *capable* of moving its herd, which may or may not be expressed in an observable choice to move). In order to facilitate inference regarding such a partially-unobservable condition, I introduce an appropriate assumption based on the context, which is reasonable based on institutional knowledge about pastoralist behavior.[7]

**Assumption.** *In a given sample period, a herder is mobile if he moves his herd away from the base camp to a waterpoint outside the village's one-day movement radius at least once.*

This is an appropriate proxy for latent mobility because in practice the weather and water supply patterns dictate that households will have to move herds of any significance outside the town's one-day movement radius, with virtually no exception. While technically this condition should be applied only to dry seasons, in practice because the survey periods imperfectly overlap wet and dry seasons, I apply the condition to all seasons in order to save on degrees of freedom. I show in robustness checks that the distinction is not qualitatively important anyway.

In the empirical implementation this assumption is implemented by carefully categorizing all waterpoints relative to a given location by whether they are local or remote, where the movement radius will be derived as part of the empirical work. I do not distinguish between base camp movements and satellite camp movements–any significant movement in response to the state of the world is considered to be an indication of mobility, whether or not the household's belongings are moved along with the herd.

[7] This assumption was verified informally through discussions with pastoralists in each of the survey towns in August, 2008.

## 3.2 Empirical Model

I use a binary choice model to capture the decision over engaging in mobile pastoralism. In order to flexibly allow for the possibility that there is a threshold effect on one's propensity to engage in mobile pastoralism, depending on herd size, I allow herd size to enter the probit specification through a flexible functional form. Hence this leads to the following empirical model, where $y$ is the latent variable representing mobility, taking the value 1 if one is mobile and 0 otherwise, and $y^*$ represents the true threshold condition on mobility. $y^*$ is assumed to be a function $f^*(z,x)$ of herd size, $z$, and other observable covariates, $x$. As in the theoretical model, in an extension of the model I will also consider the role of underlying herder "ability" (measured through an appropriate proxy). The empirical model outlined here is identical in that analysis, where the key parameter of interest, $z$, can be taken to be the 2-tuple $z = (z_h, z_a)$, where $z_h$ represents herd size and $z_a$ herder ability. $\varepsilon$ represents the distribution of unobservable influences on choice and noise:

$$y = \begin{cases} 1 & y^* \geq 0 \\ 0 & o.w. \end{cases} = \begin{cases} 1 & f^*(z,x) \geq \varepsilon \\ 0 & o.w. \end{cases}, \tag{1}$$

I want to estimate $f^*$, given a distribution of $\varepsilon$. I make the following functional-form assumption on $f^*$:

$$f^*(z,x) = h^*(z) + \beta^{*\prime}x, \tag{2}$$

where $h$ represents a (possibly highly nonlinear) function of herd size,[8] $z$, and $\beta'x$ represents the contribution of other covariates in the usual (linear) parametric way. Estimating $h^*$ is the main focus of the mobility analysis, though understanding the role of the other linear covariates contributes to secondary hypotheses.

We can also interpret this model in terms of the probability of choosing $y = 1$ (mobility),

$$\begin{aligned} P[y=1|x,z] &= P[h^*(z) + \beta^{*\prime}x \geq \varepsilon|x,z] \\ &= F_\varepsilon^*[h^*(z) + \beta^{*\prime}x]. \end{aligned} \tag{3}$$

For identification purposes, assume $F_\varepsilon^*$ is standard normal,[9] which gives location and scale, $h^*$ is real-valued continuous but unknown, and $X$ has full support. Matzkin (1992, 1994) provides general identification results on this class of models.

[8]When underlying ability is added to the analysis, $h$ naturally takes on the form $h(z_h, z_a)$.

[9]I focus on the probit model in the analysis, though it is feasible to consider alternative specifications of the error distribution.

### 3.3 Implementation

The estimation procedure, allowing for the flexible estimation of $h(z)$, is carried out using a semiparametric approach through the use of penalized splines (see, e.g., Ruppert et al., 2003). The essence of the penalized spline approach is that in addition to the usual regression optimization problem fitting a function of covariates to a response variable, it also constructs a penalty matrix, with a parameterization determining the weight of the penalty. Penalization accounts for the fact that such flexible estimation is susceptible to the overfitting trap, and hence "wigglyness" of $h$ is penalized. This leads to the following optimization problem in order to solve for the estimators,

$$\min_{f(x)\in F} \left\{ ||y - f(z,x)||^2 + \lambda P(z,x,y,f,D) \right\}, \tag{4}$$

where $\min ||y - f(z,x)||^2$ represents the usual optimization problem involved in solving for regression estimates (quadratic loss function), and $\lambda P(z,x,y,f,D)$ represents the penalty component–$\lambda$ is a penalty parameter, and $P$ a matrix product in the data with $D$, the penalty matrix. Changing the value of $\lambda$ (i.e., above 1) increases the relative weight on the penalty portion.

The estimation is carried out in the R statistical software program, using the 'mgcv' (generalized additive model) package developed by Simon N. Wood (2005, 2006, 2009). A short description of the package is provided in Appendix A.

### 3.4 Selection on Mobility

In addition to studying the (potential) threshold in herd size and ability for the household's choice to engage in mobile pastoralism, I additionally study herd *movement*, conditional on (latent) mobility. The study of movement is naturally limited to the set of households classified as mobile under the condition defined above. Hence the mobility condition acts as a selection equation for the movement data sample.

## 4 The Data

### 4.1 Background on the PARIMA Dataset and Dataset Refinements

The data was collected by the USAID Global Livestock Collaborative Research Support Program (GL CRSP) "Improving Pastoral Risk Management on East African Rangelands" (PARIMA) project. Survey data on a broad array of household demographic characteristics, herd management choices, and other consumption, labor, health and educational decisions was collected on a quarterly basis from March 2000 to June 2002 from a random selection of households, about 30 per location, at eleven locations in Northern Kenya and Southern Ethiopia. The locations were intentionally chosen in order to exhibit variation in terms of ethnic groups represented, rainfall patterns, market access, and agricultural potential (Barrett et al., 2008). For this study I focus on five of the Kenya locations: North Horr (NH), Kargi (KA), Dirib Gumbo (DG), Logologo (LL) and Suguta Marmar (SM), which exhibit appropriate variation in movement patterns, primarily due to government rangeland management policies. Controlling for minor sample attrition, I obtain a potential dataset with more than 150 Kenyan households, with 1720 household-year observations.

Further removal of observations is needed in order to have an appropriate dataset for the questions posed herein. Hence in each period I keep the sample of households with some herding animals. Observations also were dropped in cases of missing relevant data; in most cases this was because household demographic data was not available. After these exclusions I obtain an unbalanced panel dataset with 1023 household-year observations. For most of the analysis the top 5% of the herd-size distribution will be dropped as outliers. There is a very small group of wealth herders in the region, with behavior that is quite unique relative to the rest of the sample. Although removing these observations does not change the qualitative results of the analysis, it significantly improves statistical precision.

The following is an elevation map of the survey region. We see Lake Turkana in the upper left. The five main locations are highlighted with a star, and the observed waterpoints (approximately 260) accessed by people from the locations are denoted by a common shape and color. What we see is that although the waterpoints are largely separated into location-specific zones, there is important overlap of these zones, particularly in the middle of the map around Mount Marsabit, where Dirib Gumbo and Logologo are located. We also see significant migration by the herders from North Horr, venturing quite far south, and from Kargi, venturing quite far to the east. This highlights the potential for inter-tribal conflict through the search for water and forage resources.

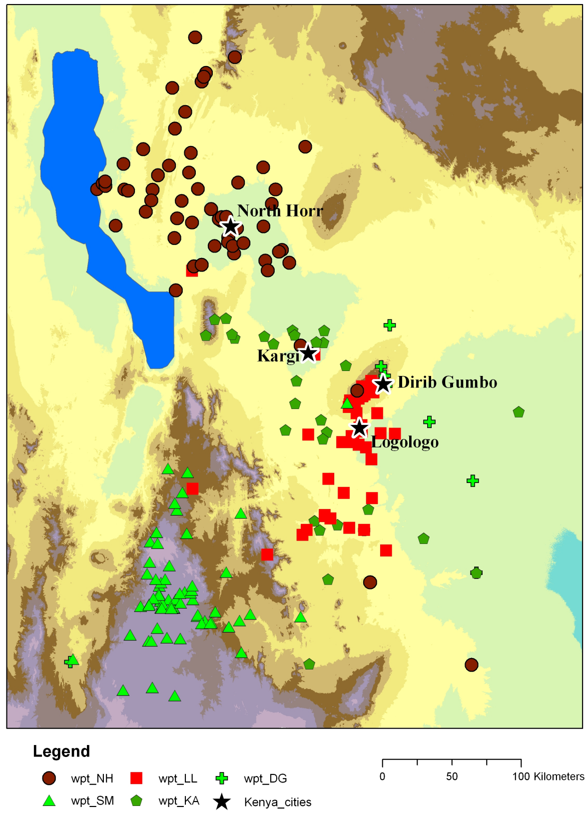



Figure. Map of survey region.

A summary description of the main explanatory variables are provided in Appendix A, along with summary statistics.

# 5 Empirical Analysis

In this section I present the empirical analysis. There are two main sections. First, I outline the results regarding the determinants of herder mobility and inferences around a mobility threshold. A number of verifications of the main result are presented, robustness checks are discussed, and I present addition evidence on the mobility boundary jointly determined by herd size per capita and ability, with ability measured using stochastic frontier efficiency estimation based on herd growth performance. Secondly, I present results on an addition test for the mobility threshold. I exploit exogenous shocks to herd size (animal deaths and thefts) that push a household below the herd-size threshold, and then study the differences in subsequent herd growth rates between the "control" group which starts above the threshold and doesn't experience such a severe shock, and the "treatment" group which is knocked below the mobility threshold. Finally, I present results on herder movement choice, conditional on satisfying the mobility condition. The main results are presented in the body of the paper, with additional graphical evidence relegated to Appendix B, and additional regression evidence to Appendix C. The sections are self-contained, with the construction of dependent variables, regression specifications and results outlined within the same subsection.

# 6 Mobility

Here I briefly note the regression setups and key terms used to distinguish between them. I will note how data subsamples are constructed in each case. I define four kinds of regression setup: basic, exogenous I and II, and endogeous. Basic regression refers to a setup in which the dependent variable is only run on the key explanatory variable (some version of herd size in TLU) and a constant. Exogenous I effects augments Basic by adding time and location dummies. Exogenous II augments Exogenous I by including individual and household-level characteristics that are realistically exogenous to the decision problem at hand: a measure of family size, the number of adult males in the household (possible lead herders), and the age of the household head and the household head's years of education and their squares. The last specification, endogenous, includes variables that could be weakly or strongly argued to be endogenous to the movement choice problem: whether the household harvested crops, whether the household had a bank account, dummy variables for 11 future concerns that households could state about the future, the proportion of largestock in the total herd's TLU (where are largestock refers to camels and cattle), and a dummy variable for whether the household had children away at school.

In fact, for each of the five dependent variables that will be described in what follows, I run five specifications. I first run the Basic specification on the entire sample. Then I truncate the sample by dropping observations for the period June 2000, as I will need to take lags of certain variables, primarily the Concerns variable (so that reported Concerns are regressed on the period they applied to). Then I essentially run the four specifications above on the slightly smaller dataset. In most cases I will not refer to these specifications by name, but rather by number, hence they will be: (1) Basic specification on full data, (2) Basic specification with period June 2000 dropped, (3) Exogenous I specification with period June 2000 dropped, (4) Exogenous II specification with period June 2000 dropped, (5) Endogenous specification with period June 2000 dropped.

To implement the mobility analysis, I use a penalized spline approach as outlined previously. All four of the possible specifications described above (basic, exogenous, endogenous I, endogenous II) are considered, where each one implies a different specification of $x$, the vector of secondary regressors.

The construction of the key dependent variable was largely outlined previously in the section on Empirical Strategy. Namely, it is a 0-1 variable that takes a value of 1 if a household has moved a portion of its herd to at least one "remote" waterpoint in the sample period, where remote is defined as a movement of at least 25 km. away from the base camp.[10] This is based on the rough rule of thumb that an animal such as a camel can travel approximately 25 km. in one day, with the idea being that such a distance only allows for movements by pastoralists who are committed to herding full-time. Hence immobile herders would not access such remote waterpoints, and this could seriously threaten the viability of their herd, lowering expected herd growth and flow benefits from the herd. This threshold is subjected to a number of checks of robustness in Appendix B, which will be discussed later. The regression specification for this part of the analysis was also outlined in the section on Empirical Strategy.

### 6.0.1 Results

The first set of results are from the semiparametric specification on mobility. The results are presented in two stages.

[10] The information on waterpoint names is based on the question "Tell me about all water points you have used to water your animals since the last interview."

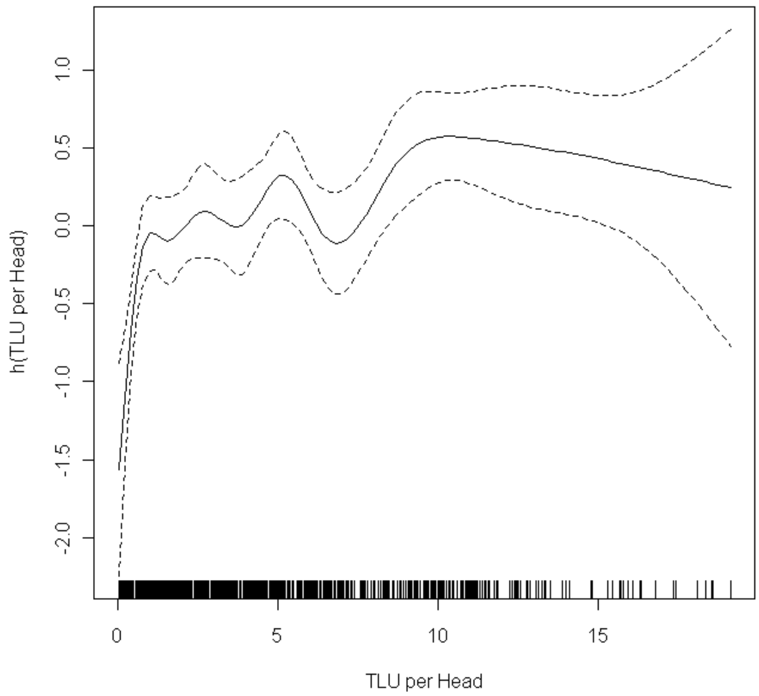



Figure. Influence of TLU per Head on Mobility.

First, the herd-influence function, presented as a flexible functional form of herd size. The above figure is generated from the "preferred" specification, (3). It can be seen that there is a very strong effect of herd size on mobility up until approximately a size of 2 TLU per head, and a continued strong influence, including through the upper limit of the error band, up to about 5 TLU per head. Then, the graph shows a number of smaller effects, which are not easily distinguishable statistically, with the most noticeable a small dip around 7.5 TLU per head. Finally, the graph rises up again at about 10 TLU per head. As of about 10 TLU per head the function seems to decline slightly, though at this point statistical precision begins to disperse due to the lack of observations.

These results can be compared to the results presented in the Introduction, on previous work looking at the bifurcation in asset accumulation dynamics. We would expect that if the main hypothesis in this paper about mobility as the key factor driving asset dynamics is valid, then the threshold in the incentive to engage in mobile pastoralism should roughly match the bifurcation in asset accumulation dynamics. In Lybbert et al. (2004) we see that (with herd size in logs), that the bifurcation point in herd size dynamics occurs as of about 2.25. Once this number is converted back to regular form, it seems that the key threshold is at about 10 TLU (i.e., $e^{2.25} = 9.49$). Given that mean normalized household labor supply is at just under 4, it appears that the strongest mobility effect of TLU per head seems to match well with that work. In addition, we see a strong continued effect up to about 2.6; with $e^{2.6} = 13.46$, the final threshold effect seems somewhat lower (once converted into terms of TLU per head) but this may be due to contextual differences. Looking at the results in Barrett et al. (2006), which are already converted into TLU per head, we find that again the results match quite consistently. The noticeable mobility effect occurs up to about 5 TLU per head, which is the crossing point in that latter paper, and then the upper, stable dynamic asset accumulation equilibrium is at about 10 TLU per head, after which the effect of herd size seems to level off. Hence it appears that there is a strong threshold effect in mobility, which seems to be closely connected to the poverty trap thresholds we observe in the asset accumulation analysis in prior work.

This result is subjected to a number of robustness checks in Appendix B. These include: controls for other variables than herd size, variations in the definition of mobility (i.e., thresholds different from 25 km.), running the data only on dry season or wet season data, and varying the definition of outliers. From each of these robustness checks we see support for the main argument: that there is a threshold effect in movement to waterpoints beyond about one day's travel, and the strongest part of the threshold effect occurs approximately at the bifurcation point in asset accumulation dynamics that is observed in the prior literature.

However, the graph of the flexible functional form representation of herd-size influence is only part of the story. In addition, the semiparametric approach (as opposed to a fully nonparametric approach) allows for a number of other explanatory variables to be run. These are run linearly, and the results for the five regression specifications are given in the following table.

| Variable | (1) | | se | (2) | | se | (3) | | se | (4) | | se | (5) | | se |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Dec 2000 | | | | | | | -0.06736 | | 0.18304 | -0.066925 | | 0.1882419 | -0.00145 | | 0.1951646 |
| Mar 2001 | | | | | | | -0.43533 | ** | 0.19015 | -0.4342391 | ** | 0.1955498 | -0.3982773 | ** | 0.2014195 |
| June 2001 | | | | | | | -0.31133 | * | 0.18918 | -0.3020035 | | 0.1947619 | -0.2996179 | | 0.2084108 |
| Sept 2001 | | | | | | | -0.40466 | ** | 0.18992 | -0.3722421 | * | 0.1950823 | -0.3531379 | | 0.2042109 |
| Dec 2001 | | | | | | | -0.81837 | *** | 0.20127 | -0.8049586 | *** | 0.206097 | -0.7180031 | * | 0.2229658 |
| March 2002 | | | | | | | -0.36634 | * | 0.19759 | -0.3902377 | * | 0.2038896 | -0.3065791 | *** | 0.2157513 |
| June 2002 | | | | | | | -0.75108 | *** | 0.20975 | -0.7569213 | *** | 0.2155669 | -0.7054593 | | 0.2230797 |
| Kargi | | | | | | | 0.7048 | *** | 0.21749 | 0.6677241 | *** | 0.2289817 | 1.387607 | *** | 0.4115941 |
| Logologo | | | | | | | 1.07643 | *** | 0.18451 | 1.1409021 | *** | 0.1943366 | 1.2150826 | *** | 0.3280258 |
| North Horr | | | | | | | 1.56871 | *** | 0.20977 | 1.4394345 | *** | 0.2190975 | 1.5688354 | *** | 0.3976523 |
| Suguta Marmar | | | | | | | 1.16533 | *** | 0.19362 | 1.1773573 | *** | 0.2032108 | 1.2705219 | *** | 0.3081645 |
| Family labor | | | | | | | | | | -0.0157117 | | 0.0573423 | 0.0195642 | | 0.06056 |
| # adult male | | | | | | | | | | 0.0265983 | | 0.0744298 | -0.002544 | | 0.07783 |
| H-hold head male | | | | | | | | | | 0.2177808 | * | 0.1234607 | 0.1191122 | | 0.1337733 |
| Age h-hold head | | | | | | | | | | 0.0415779 | | 0.0280639 | 0.0357899 | | 0.028518 |
| Age h-hold head^2 | | | | | | | | | | -0.0003047 | | 0.0002679 | -0.0002451 | | 0.0002744 |
| Head years education | | | | | | | | | | -0.123101 | * | 0.071242 | -0.1021992 | | 0.0743115 |
| Head years education^2 | | | | | | | | | | 0.0125812 | * | 0.0065505 | 0.0108695 | | 0.0068205 |
| Crops harvested | | | | | | | | | | | | | -0.1603821 | | 0.272179 |
| Bank account | | | | | | | | | | | | | -0.1794006 | | 0.2205736 |
| Concern: pasture for animals | | | | | | | | | | | | | 0.3458761 | * | 0.2030619 |
| Concern: water for animals | | | | | | | | | | | | | 0.0012083 | | 0.194638 |
| Concern: animal sickness/death | | | | | | | | | | | | | -0.2659096 | | 0.2272844 |
| Concern: animal theft/raiding | | | | | | | | | | | | | 0.2968772 | | 0.23983 |
| Concern: Insecurity/violence/fights | | | | | | | | | | | | | 0.276888 | | 0.2476293 |
| Concern: Human sickness | | | | | | | | | | | | | 0.0343206 | | 0.2459856 |
| Concern: No buyers for animals | | | | | | | | | | | | | -0.4709438 | * | 0.2619477 |
| Concern: Low prices for animals | | | | | | | | | | | | | -0.296478 | | 0.2506551 |
| Concern: Not enough food | | | | | | | | | | | | | -0.1134606 | | 0.1950024 |
| Concern: High prices | | | | | | | | | | | | | 0.1915252 | | 0.2542297 |
| Concern: Crop failure | | | | | | | | | | | | | 0.1581234 | | 0.1873362 |
| Proportion largestock | | | | | | | | | | | | | -0.0652549 | | 0.332078 |
| Kids away at school | | | | | | | | | | | | | -0.2259276 | * | 0.1306601 |
| Constant | -0.33 | *** | 0.04425 | -0.36552 | *** | 0.04736 | -0.96372 | *** | 0.18879 | -2.3079086 | *** | 0.703333 | -2.258914 | *** | 0.8174718 |
| h(TLU per head) | | | | | | | | | | | | | | | |
| edf. | 8.46 | | | 8.295 | | | 8.631 | | | 8.476 | | | 8.519 | | |
| Ref. df. | 8.46 | | | 8.295 | | | 8.631 | | | 8.476 | | | 8.52 | | |
| Chi. Sq. | 93.82 | | | 75.81 | | | 39.19 | | | 36.33 | | | 27.89 | | |
| Log-likelihood | -563.44 | | | -493.8711 | | | -438.3148 | | | -417.3381 | | | -405.2403 | | |
| p-value | 0.00 | *** | | 4.83E-13 | *** | | 7.84E-06 | *** | | 2.27E-05 | *** | | 0.000718 | *** | |
| R-squared (adj.) | 0.10 | | | 0.0877 | | | 0.207 | | | 0.217 | | | 0.232 | | |
| UBRE score | 0.24 | | | 0.2378 | | | 0.12902 | | | 0.12897 | | | 0.13645 | | |
| n | 931 | | | 813 | | | 813 | | | 788 | | | 788 | | |
| *** Sig. at 1%, ** sig. at 5%, * sig. at 10%. | | | | | | | | | | | | | | | |

Table. Main mobility regressions.

In the statement of results from semiparametric regressions, UBRE stands for "Un-Biased Risk Estimator", which is basically the gam equivalent of the AIC criterion. The computer package selects the best spline specification through the use of the UBRE. The package provides information on assessing the "significance" of the spline function.

### 6.0.2 Further Assessment of Mobility Result

In this section I present further assessment of the mobility result, including testing and representation, and further study which incorporates the consideration of herder ability. Throughout the results from specification (1) of the semiparametric model are employed.

**Response Function** The Figure above, which represents the $h^*$ function presenting the influence of herd size per capita on mobility, can only be interpreted qualitatively; i.e., the response values on the $y$-axis only have meaning in the context of the probit. The following graph provides a more useful iteration of that result–it calculates the predicted response values based on the estimated function, taking the other values at their means. This provides perhaps a more useful representation of expected response, where now the values on the $y$-axis can be interpreted as the propensity to engage in mobile pastoralism. Again we see a confirmation of the above results.[11]

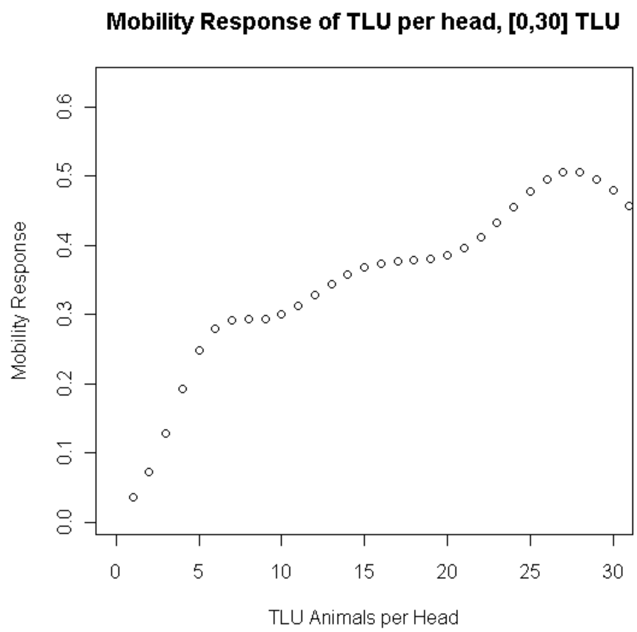



Figure. Response plot.

**Derivative Test** A key question about the estimated flexible function is over what ranges it is (strictly) increasing or decreasing. The following graph provides an initial approach to this question. We see that the derivative of the herd influence function is strictly positive (even according to its error bands) below about 2 TLU per head, while it is testably below non-positive (including error bands) as of just above 5 TLU per head. It can also be seen that apart from a short segment at around 8 TLU per head, elsewhere the slope of the function is not testably different from zero. However, this seems supportive of my initial result on a threshold effect in the mobile pastoralism livelihood.

[11] The estimation beyond 15 TLU per head is largely out of sample, hence it should be interpreted with more caution.

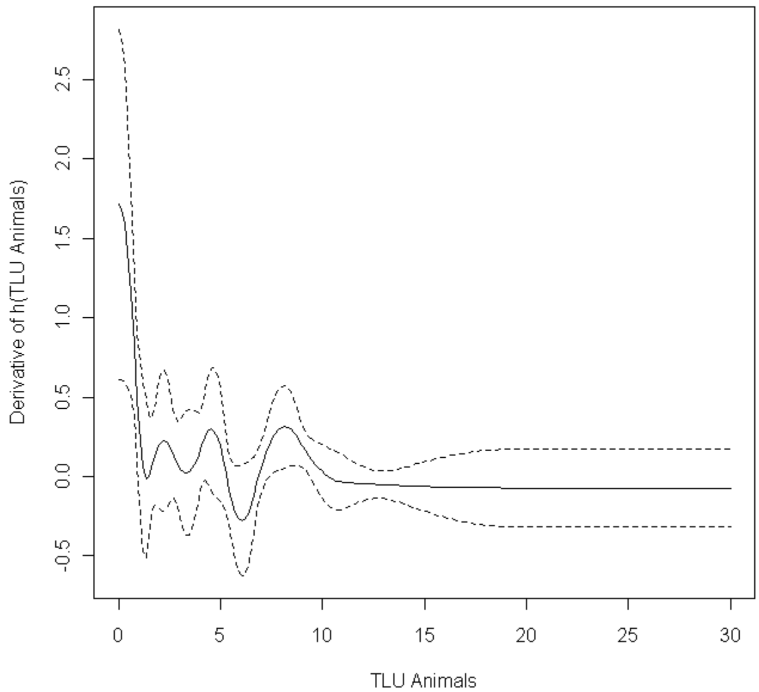



Figure. Graph of derivative with errors.

**Comparison to Parametric Model** A key question about semiparametric methods is: what do they buy us beyond a (simpler) parametric model? Why not just run a very flexible functional form in the key response variable(s)? This subsection presents a preliminary approach to this question, by employing a Chi-square test for a statistically significant difference between the semiparametric spline in a generalized additive model framework, and a standard parametric functional form, with a 4th-order polynomial in herd size. With a p-value of 0.02296, the test indicates that the two models are statistically significantly different, within the 5% rule of thumb.

## 6.1 Herd Mobility and Ability

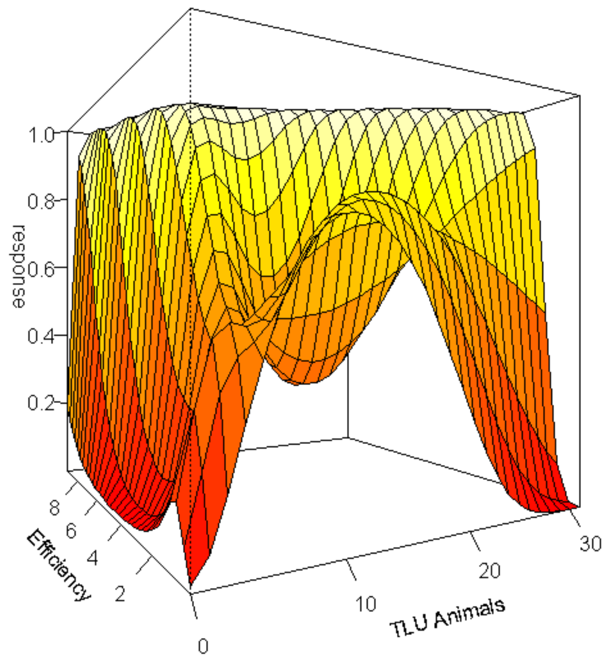
I carry a final application in this section. Following the procedure of Santos and Barrett (2006) I use stochastic production frontier efficiency estimates to derive a measure of unobserved herder ability. Taking herd growth as the dependent variable (output), inefficiency is then measured as the degree to which a household is below the (population) herd growth frontier. An inversion of the inefficiency estimate provides a measure of efficiency. I then use the efficiency estimates as explanatory variables in a higher-dimensional analysis of potential thresholds in mobility choice: I take households to hold two assets, TLU per head and ability, and look at an estimated joint smooth function.

The first step is to carry the stochastic production frontier estimates, in which I follow Santos and Barrett (2006) as much as possible. The following is the output from that estimation. The first 8 terms of 2 sets of 4 variables capture the effect a 4th-order quadratic function of herd size in TLU interacted with whether or not a household is above or below a threshold of TLU per head of 5. The 9th and 10th covariates are analagous representations interacted with family size (i.e., labor availability).

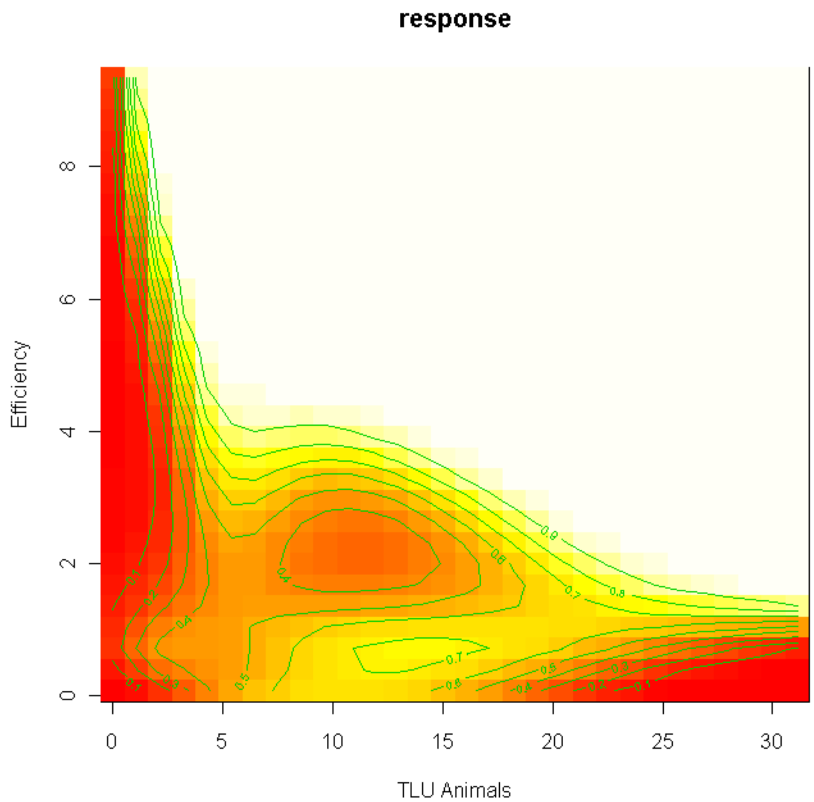
```
Time-invariant inefficiency model                 Number of obs      =       758
Group variable: master                            Number of groups   =       127

                                                  Obs per group: min =         1
                                                                 avg =       6.0
                                                                 max =         8

                                                  Wald chi2(21)      =    101.75
Log likelihood  = -1333.7421                      Prob > chi2        =    0.0000
```

| herd_grow | Coef. | Std. Err. | z | P>\|z\| | [95% Conf. | Interval] |
|---:|---:|---:|---:|---:|---:|---:|
| tlu_ph~b_thr | -.7104028 | .1581082 | -4.49 | 0.000 | -1.020289 | -.4005165 |
| tlu_~b_thr_2 | .0675137 | .0235933 | 2.86 | 0.004 | .0212716 | .1137557 |
| tlu_~b_thr_3 | -.0025805 | .0012685 | -2.03 | 0.042 | -.0050668 | -.0000943 |
| tlu_~b_thr_4 | .0000339 | .0000214 | 1.58 | 0.114 | -8.15e-06 | .0000759 |
| tlu_ph~l_thr | -1.877882 | .2783078 | -6.75 | 0.000 | -2.423356 | -1.332409 |
| tlu_~l_thr_2 | .6000454 | .1057291 | 5.68 | 0.000 | .3928203 | .8072706 |
| tlu_~l_thr_3 | -.0701102 | .0138608 | -5.06 | 0.000 | -.0972769 | -.0429436 |
| tlu_~l_thr_4 | .0025408 | .0005509 | 4.61 | 0.000 | .0014611 | .0036206 |
| fam_size_a~r | .0999652 | .0875929 | 1.14 | 0.254 | -.0717138 | .2716442 |
| fam_size_b~r | -.1524821 | .0608099 | -2.51 | 0.012 | -.2716674 | -.0332969 |
| no_tlu_lag | (omitted) | | | | | |
| head_edu | -.0550172 | .0690792 | -0.80 | 0.426 | -.19041 | .0803756 |
| head_edu_2 | .0074316 | .0067106 | 1.11 | 0.268 | -.0057208 | .0205841 |
| age_head | .0610892 | .027939 | 2.19 | 0.029 | .0063297 | .1158487 |
| age_head_2 | -.0006067 | .0002688 | -2.26 | 0.024 | -.0011335 | -.0000798 |
| head_gender | .1192147 | .1233994 | 0.97 | 0.334 | -.1226437 | .3610731 |
| adult_male | .0347878 | .0758629 | 0.46 | 0.647 | -.1139007 | .1834763 |
| dry | -.0992959 | .1024527 | -0.97 | 0.332 | -.3000996 | .1015078 |
| loc_DG | -.5831049 | .1801676 | -3.24 | 0.001 | -.9362269 | -.229983 |
| loc_KG | -.1276476 | .2188012 | -0.58 | 0.560 | -.5564901 | .3011948 |
| loc_LL | -.2246186 | .1819955 | -1.23 | 0.217 | -.5813232 | .132086 |
| loc_NH | -.5433199 | .213432 | -2.55 | 0.011 | -.9616389 | -.1250009 |
| _cons | 1.010738 | .6937634 | 1.46 | 0.145 | -.3490134 | 2.370489 |
| /mu | -13.25445 | 735.6328 | -0.02 | 0.986 | -1455.068 | 1428.559 |
| /lnsigma2 | .84746 | 8.360904 | 0.10 | 0.919 | -15.53961 | 17.23453 |
| /ilgtgamma | -1.707788 | 54.48343 | -0.03 | 0.975 | -108.4934 | 105.0778 |
| sigma2 | 2.333712 | 19.51194 | | | 1.78e-07 | 3.05e+07 |
| gamma | .1534508 | 7.077597 | | | 7.62e-48 | 1 |
| sigma_u2 | .3581099 | 19.51115 | | | -37.88303 | 38.59925 |
| sigma_v2 | 1.975602 | .1018551 | | | 1.775969 | 2.175234 |

What follows is a 3-dimensional plot of the joint effect of TLU per head and ability on the threshold in mobility choice. It can be seen here that one's propensity to engage in mobile pastoralism is quite high if one is of very high efficiency or high TLU herd size (or both). When both efficiency and herd size are lower, we see that the relationship is much more tenous: herders are not as likely to engage in mobile pastoralism.




The result can be seen more starkly in the following diagram, which is of the same object, only from an overhead "contour" profile. Here we see the suggestion of an "isoquant" frontier which exhibits the roughly convex tradeoff in efficiency (ability) and herd size, in terms of a household's propensity to engage in mobile pastoralism.




## 6.2 Additional Inferences Around the Threshold

As an additional test of the mobility threshold hypothesis, I look at a "natural experiment" in the data. The theory assumes that herd growth rates should differ above and below the mobility threshold, as herd households make use of two different herd growth technologies. In particular, when animals do not migrate during dry seasons they may receive lower nutrient inputs due to a lack of resources in the villages, and hence have lower growth rates. We would also expect that herd growth would suffer at small herd sizes simply due to the biology of reproduction.

Hence I look at the following test. I consider herd-growth rates from two classes of households. The "treatment" sample is the subset of households that begin above the mobility threshold, and through plausibly exogenous shocks to herd stock (animal death, and loss due to theft) are shocked below the mobility threshold. The "control" sample is constituted by households that begin above the threshold and remain there. I then compare the subsequent herd-growth rates of the two groups. Under a number of specifications (for mobility threshold, and appropriate truncation of the sample at 8, 10 and 12 TLU per head, in order to have a consistent comparison), I find that the expected difference in herd growth rates does indeed hold consistently, although the difference is never at a statistically significant level. This may simply be due to sample size issues. Hence I do not report these results in the paper, though they are available upon request.

### 6.3 Movement

I provide evidence on the herd movements of households that are classified as mobile. As discussed previously, I use mobility as a selection condition to identify the set of observations for this part of the study. I use three main measures to quantify movement choices, running them as dependent variables in appropriate empirical specifications for their sampling properties, which will be described shortly. The three measures are a normalized measure of number of movements per quarter, two measures of time spent at given waterpoints, and each mobile household's maximum distance traveled in each quarter. Histograms summarizing the empirical distributions of each of the dependent variables are provided at the end of Appendix A. Throughout I index individual herder households by $i$ and time periods (quarters) by $t$.

First, an index of the number of waterpoints visited in a period. It is calculated as the number of waterpoints visited by a household in a quarter, divided by the number of animal types of a herder within the categories of camels, cattle and smallstock. Hence the variable is not biased by the fact that herders with more animal types are naturally more likely to visit more waterpoints due to different animal dietary preferences. The regression setup is as follows,

$$\text{Num\_movements}_{it} = \max\left(0, \beta_0 + h_{it}\beta_{11} + h_{it}^2\beta_{12} + X_t\boldsymbol{\beta}_2 + \varepsilon_{it}\right) \tag{5}$$

where $\text{Num\_movements}_{it}$ is the dependent variable for (normalized) number of herd movements per household in period $t$, $h_{it}$ is the herd size of household $i$ in period $t$ in TLU per capita, $X_{it}$ represents a set of additional regressors, and $\varepsilon_{it}|h_{it}, h_{it}^2, X_t \sim N\left(0, \sigma^2\right)$.

Second, the measure of time spent at waterpoints involves an adaptation of the Herfindahl index. In this context it is used as a measure of the "agglomeration in remote waterpoint visits"–if large portions of the herd spend many weeks at a few or one remote waterpoint, then the index will take a higher value. I first calculate the following index:

$$\zeta_x^l\left(t\right) = \frac{\tau_x^l\left(t\right)}{13}, \tag{6}$$

where $\zeta_x^l\left(t\right)$ represents the time allocation to a waterpoint $x$ in a given sample period (quarter) by subherd $l$, $\tau_x^l$ represents the duration of time subherd $l$ spends at location $x$ in period $t$, and 13 is a normalization by total available weeks for a subherd in a given period. The Herfindahl-Time index is then constructed as follows in a period $t$ for a given herder:

$$HT_t = \sum_x \left(\zeta_x^l(t)\right)^2, \tag{7}$$

which is meant to take values between zero and one.

The second version of the Herfindahl index is meant to capture the idea that we might want to consider the *size* of the herd being sent to each remote waterpoint for given time periods, to provide a herd-weighted sense of allocation to remote waterpoints. In this case the appropriate preliminary index is:

$$\lambda_x^l(t) = \frac{h_x^l(t)\,\tau_x^l(t)}{13 \cdot h(t)}, \tag{8}$$

where $\lambda_x^l(t)$ represents the herd-time allocation to a waterpoint $x$ in a given sample period (quarter) by subherd $l$, where $h_x^l(t)$ is the size of the herd $l$ allocated to location $x$ in period $t$, $\tau_x^l$ represents the duration of time subherd $l$ spends at location $x$ in period $t$, and $13 \cdot h(t)$ is a normalization by total available herd-weeks. The Herfindahl-Herd-Time index is then constructed as follows in a period $t$ for a given herder:

$$HHT_t = \sum_x \left(\lambda_x^l(t)\right)^2, \tag{9}$$

which is meant to take values between zero and one.

Since the Herfindahl index variable is also a censored dependent variable (between 0 and 1) I again use a Tobit specification. It is similar to the case for number of movements,

$$\text{Herf}_{it} = \max\left(0, \beta_0 + h_{it}\beta_{11} + h_{it}^2\beta_{12} + h_{it}^3\beta_{13} + X_t\boldsymbol{\beta}_2 + \varepsilon_{it}\right)$$

where $\text{Herf}_{it}$ is the dependent variable for the Herfindahl index as described above (which can represent $HT_{it}$ or $HHT_{it}$), $h_{it}$ is the herd size of household $i$ in period $t$ in TLU per capita (allowing for squared and cubed terms permitting additional functional flexibility), $X_{it}$ represents a set of additional regressors, and $\varepsilon_{it}|h_{it}, h_{it}^2, X_t \sim N(0, \sigma^2)$.

The third dependent variable constructed in the analysis of movement is a representation of the distance traveled by a household's herds in a given period. Given that we observe movements for a number of subherds of a given household, there are a number of measures that one could construct to get distance traveled in response to certain observables. In this case I focus on the maximum distance traveled, which is measured as the shortest distance in kilometers from the household's central location to a given waterpoint.

Since a number of the "movements" in this sample involve zero distance moved (even though at least one movement will be significant), it will again be necessary to use a Tobit regression to account for censoring at zero. Otherwise the structure is largely the same as that used in the analysis of time spent at waterpoints:

$$\text{Distance}_{it} = \max\left(0, \beta_0 + h_{it}\beta_{11} + h_{it}^2\beta_{12} + h_{it}^3\beta_{13} + X_t\boldsymbol{\beta}_2 + \varepsilon_{it}\right),$$

where $\text{Distance}_{it}$ represents the maximum distance moved, and the right-hand-side variables are the same as in previous specifications.

### 6.3.1 Results

In this section I present the regression results on movement. The regressions presented here are not presented so much as a test of the implications of the guiding model in this paper, but rather as a way to generate stylized facts on the movement choices involved in mobile pastoralism, based on the mobility selection criterion implied by the preceding analysis. Here a selection criterion is applied so that only "mobile" observations are retained. I again remove the top 5% observations on the TLU distribution as outliners. The key results on movement, for (1) Number of movements in a sample quarter, (2) Time spent at waterpoints, and (3) Maximum distance traveled, are presented in Appendix C, and summarized briefly here.

The main result for Number of Movements is that larger herd size tends to predict less movement, perhaps suggesting that better herders are able to maintain larger herds by better selecting locations to move to, or that larger herds are able to better compete for scarce water and forage resources. Second, based on the constructed Herfindahl index, results seem to indicate that price and market effects are most important in determining the herd size-weighted time allocation variable: cropping activities, and concerns about market prices for both purchases and livestock sales are the significant variables in this regression. Third, I run the maximum distance travelled by a household in a given period as a dependent variable, as a measure of distance travelled. The results are surprising in that very few variables are statistically significant; about all that is significant are the location dummies on the driest locations (where we might expect the longest movements, as the herders will have to travel long distances in the search for viable water and forage resources).

# 7 Conclusion

This paper provides an empirical analysis of the determinants of mobility and movement in a pastoralist population in northern Kenya, which has implications for other arid and semi-arid regions in east Africa and beyond.

Most importantly, the analysis provides support for the hypothesis that mobility is the key determinant of the bifurcation point in herd accumulation dynamics observed in other research on this population. The quantitative estimate of where the herd-size threshold might occur is useful for policymakers concerned with herd-restocking or attempts to promote sustainable pastoralism in the region as a means to combat poverty. Secondly, the paper provides further evidence on the determinants of movement in the population, which may be of further interest to policymakers concerned with environmental degradation and ethnic conflict in the region.

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# Appendix A: Summary Statistics, Graphical Data Summaries, and Description of Variables

## 7.1 Discussion of mgcv Package

mgcv is a package designed to fit generalized additive models (GAMs). The 'generalization' referred to is the allowance for the estimation of smooth functions of covariates. GAMs build on the framework of Generalized Linear Models (GLMs), which are a class of models that uses a link function to connect the covariates to the response variable, and includes probit and logit models, among others. The model fit is given by penalized cubic spline regressions, wher e the knot points, spline bases and penalty parameters ($\lambda$) are chosen according to the Un-Biased Risk Estimator, which is essentially the natural extension of the AIC criterion to this class of models.[12] As noted above, in order to

[12] mgcv allows for alternative criteria for the selection of the smoothness parameter, including Generalized Cross Validation (GCV) and Restricted Maximum Likelihood (REML).

achieve identification in this class of models a scaling assumption is needed, which is implemented through setting the parameter scale=1.

## Summary Statistics

I provide summary statistics based on the data sample used most commonly in the analysis, after dropping missing observations and outliers above the 95th percentile of the remaining distribution of TLU per unit of household labor, leaving an unbalanced panel dataset with 931 observations.[13] The first table provides summary statistics on the distribution of herd size in TLU. The second table provides summary statistics on household labor, recalling the formula that a weight of 0 is given to houshold members between 0 and 8 years of age; a weight of 0.5 is given to children between 9 and 15, and adults 55 and above; and full unit weight is given to household members between the ages of 16 and 54.

The correlation between TLU Animals and household labor supply is 0.1394, which seems rather low. This may suggest that the distribution of herding ability is fairly dispersed. In addition, if herd size represents a long-run dynamic equilibrium as a function of herder ability on average, then the relatively low correlation might suggest that household fertility behavior is not terribly responsive to long-run herd dynamics, which would reduce concerns about the endogeneity of household labor supply.

**TLU Animals**

| | Percentiles | Smallest | | |
|---|---|---|---|---|
| 1% | 0.3 | 0.1 | | |
| 5% | 1.0 | 0.1 | | |
| 10% | 2.1 | 0.2 | Obs | 931 |
| 25% | 4.5 | 0.2 | Sum of Wgt. | 931 |
| 50% | 11.1 | | Mean | 15.141 |
| | | Largest | Std. Dev. | 13.320 |
| 75% | 23.0 | 62.4 | | |
| 90% | 34.5 | 68.0 | Variance | 177.432 |
| 95% | 39.7 | 71.5 | Skewness | 1.291 |
| 99% | 55.9 | 98.1 | Kurtosis | 5.164 |

Summary Statistics on Herd Size in TLU.

[13] The cutoff occurs at 19.283 TLU per unit of household labor.

**Family Labor***

| | Percentiles | Smallest | | |
|---|---|---|---|---|
| 1% | 1.0 | 0.5 | | |
| 5% | 1.5 | 0.5 | | |
| 10% | 2.0 | 0.5 | Obs | 931 |
| 25% | 2.5 | 0.5 | Sum of Wgt. | 931 |
| 50% | 3.5 | | Mean | 3.744 |
| | | Largest | Std. Dev. | 1.645 |
| 75% | 4.5 | 9.5 | | |
| 90% | 6.0 | 9.5 | Variance | 2.705 |
| 95% | 7.0 | 9.5 | Skewness | 0.808 |
| 99% | 9.5 | 9.5 | Kurtosis | 3.945 |

*Age 0-8 = 0, 9-15 = 0.5, 16-54 = 1, 55+ = 0.5

Family labor supply in TLU.

## Histograms

The histogram of the variable recording herd size in TLU per unit of household labor.

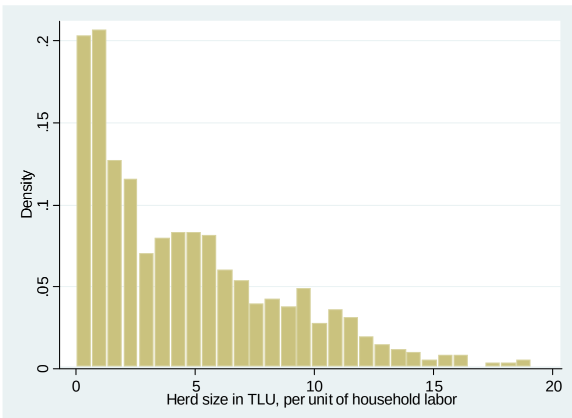



Figure. Distribution of TLU per unit household labor, up to 95th percentile.

## Explanatory Variables

Here are some brief notes on the meaning of further independent variables (including the survey questions used to elicit them). Note that for the concern variables, I used lagged values, since the herders were asked to make a projection into the future quarter. Hence when I run a regression on the full dataset with the concern controls, I must drop the observations for the first time period (June 2000).

- (Month) xxxx dummy. Dummy variable taking value 1 in the specified time period, where the Month (March, June, September, December) and year are given (the latter by xxxx, either 2000, 2001, or 2002).

- X location dummy. Dummy taking value 1 for an observation in a given location. There are five locations used in the analysis: Dirib Gumbo (DG), Kargi (KG), Logologo (LL), North Horr (NH), and Sugata Marmar (SM). DG is always used as the control dummy.

- Herd size in TLU. Herd size in tropical livestock units. Herders were asked to report their household herd size at each quarterly survey round, including counts of male and female camels, cattle, sheep and goats. The value of the herd size *prior* to a given round is used in the regressions (assuming movements depend most on the herd size entering the period). Hence the herd size is "lagged forward" in some sense.

- Normalized family size. A measure of available family labor is given. Adults between the ages of 16 and 54 are given a value of 1, while children between 8 and 15 and the elderly are given a value of 0.5, and infants and young children are given a labor value of 0.

- # adult male. The number of adult males in the household (assumed as a proxy for herding labor supply).

- H-hold head dummy. Takes a value of 1 if the household head is male.

- Age hhold head. The age of the household head, in years.

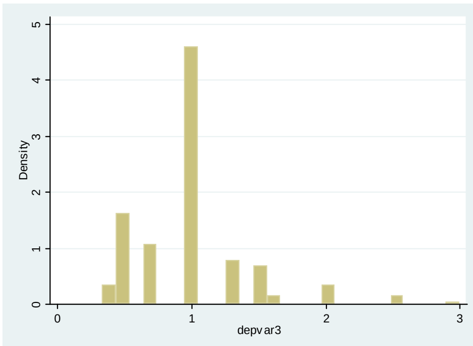
- Head years education. The household head's years of education in years.

- Crops harvested dummy. Has your household harvested any crops since the last interview? (Y/N)

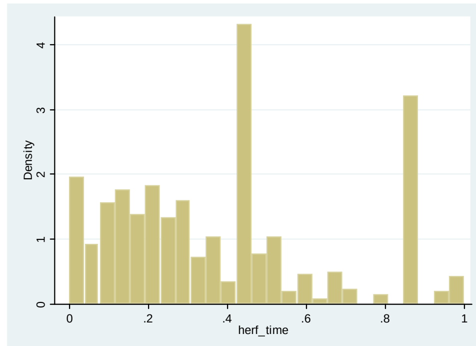
- Current have bank account dummy. Do you currently have a bank account? (Y/N)

- Concern: pasture for animals. Are you concerned with: Not enough pasture for animals? (Y/N)
- Concern: water for animals. Are you concerned with: Not enough water for animals? (Y/N)
- Concern: animal sickness/death. Are you concerned with: Animal sickness / death? (Y/N)
- Concern: animal theft/raiding. Are you concerned with: Animals loss due to theft / raiding? (Y/N)
- Concern: Insecurity/violence/fights. Are you concerned with: Insecurity / violence / fights? (Y/N)
- Concern: Human sickness. Are you concerned with: Human sickness? (Y/N)
- Concern: No buyers for animals. Are you concerned with: No buyers for animals you wish to sell? (Y/N)
- Concern: Low prices for animals. Are you concerned with: Low prices for animals you wish to sell? (Y/N)
- Concern: Not enough food for ppl. Are you concerned with: Not enough food for people? (Y/N)
- Concern: High prices for purchases. Are you concerned with: High prices for things you buy? (Y/N)
- Concern: Crops fail. Are you concerned with: Crops fail? (Y/N)
- Proportion of largestock in herd. Proportion of tlu of the herd in cattle or camels (as a fraction of total tlu).
- Kids away at school (dummy). Takes a value of 1 if the household has children away at school.

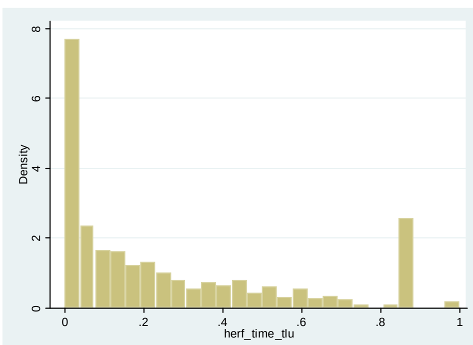
## 7.2 Histograms for the Dependent Variables for Movement



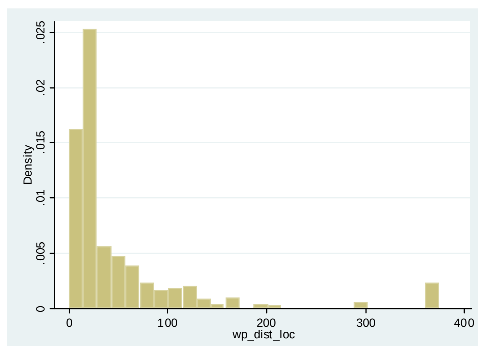

Normalized number of movements made per quarter.




Histogram for herf_time; Herfindahl on time spent.




Histogram for herf_time_tlu (herd-weighted time spent).




Histogram for max. distance travelled in a quarter.

# Appendix B: Graphical Presentation of Results

## Mobility

In this section I present the graphs of the flexible function of TLU Animals, for a number of data sample sizes, and regression specifications.

### Additional Graphs for Main Mobility Regression

The following graphs depict the influence function for TLU per Head for the specifications (1), (2), (4) and (5).

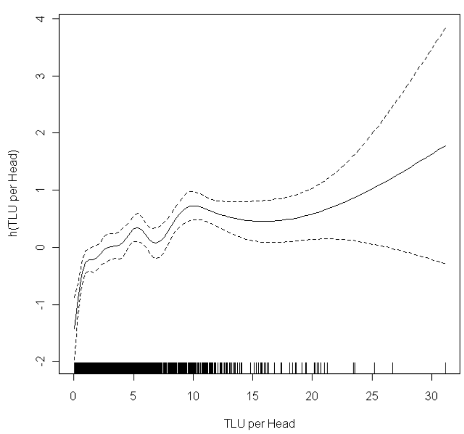



Figure. Spec. (1).

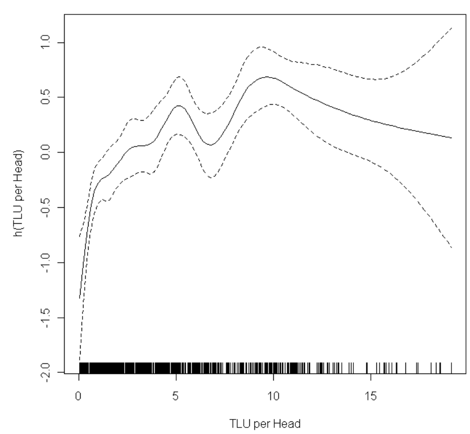



Figure. Spec. (2).

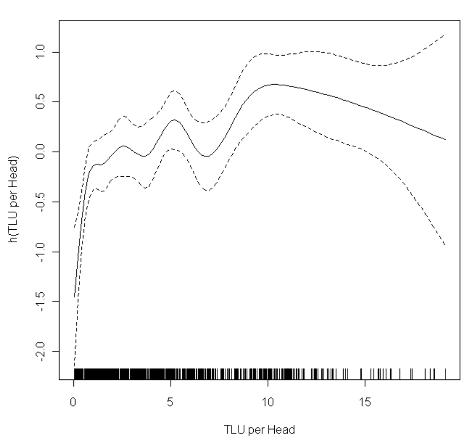



Figure. Spec. (4).

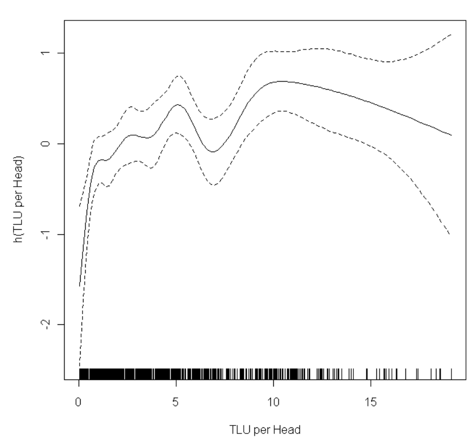



Figure. Spec. (5).

## 7.3 Robustness for Main Mobility Regression

**Graphs of Herd-Size Influence Function at Various Herd-size Thresholds**

Here we consider the herd-size influence function on the basic specification (specification (1)), with the distance threshold necessary to define mobility and thresholds varying from 5 to 35. Sample size is also identical to specification (1): it eliminates outliers above the 95th percentile of the herd-size distribution, but includes period June 2000.

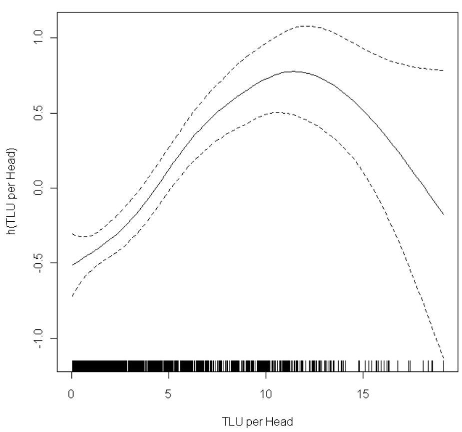



Figure. Threshold 5 km.

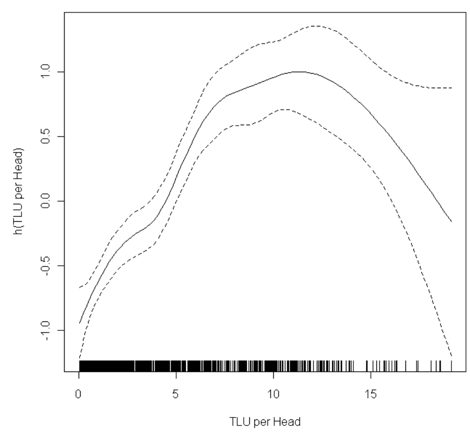



Figure. Threshold 10 km.

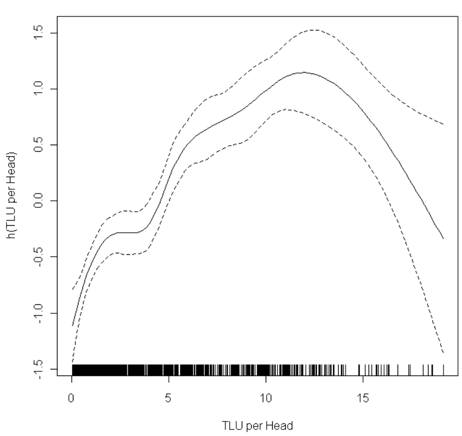



Figure. Threshold 15 km.

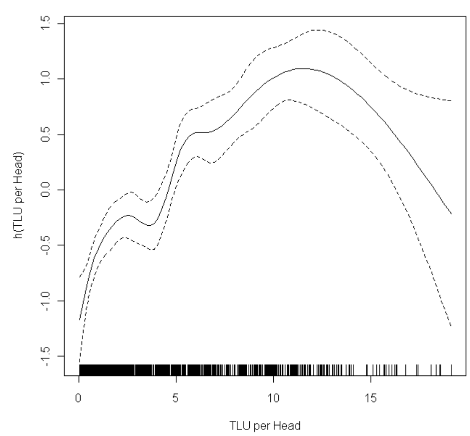



Figure. Threshold 20 km.

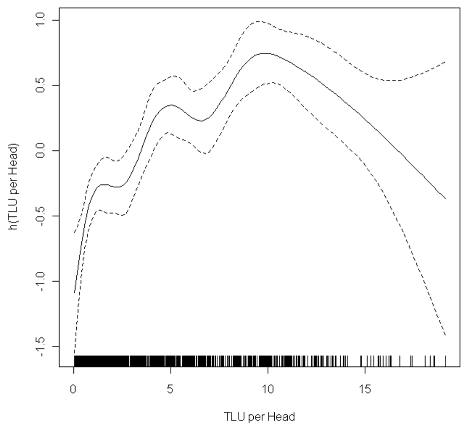



Figure. Threshold 30 km.

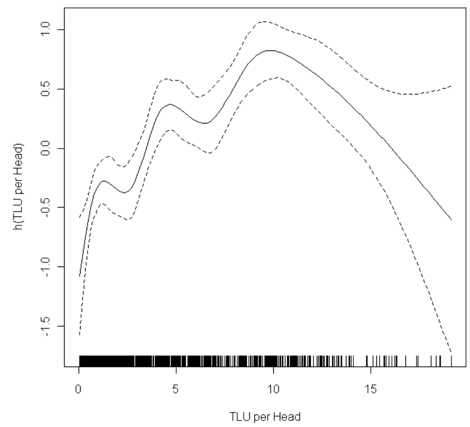



Figure. Threshold 35 km.

# Appendix C: Regression Results

### Number of Movements

| | (1) | | (2) | | (3) | | (4) | | (5) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Herd size in TLU | 0.0022 | (0.0069) | 0.0045 | (0.0075) | 0.0003 | (0.0078) | 0.0016 | (0.0082) | 0.0020 | (0.0094) |
| Herd size in TLU squared | -0.0001 | (0.0001) | -0.0001 | (0.0002) | -0.0000 | (0.0002) | -0.0000 | (0.0002) | -0.0000 | (0.0002) |
| December 2000 dummy | | | | | 0.1762** | (0.0823) | 0.1790** | (0.0846) | 0.1952** | (0.0860) |
| March 2001 dummy | | | | | 0.0240 | (0.0945) | 0.0069 | (0.0967) | 0.0343 | (0.1000) |
| June 2001 dummy | | | | | -0.1454 | (0.0888) | -0.1549* | (0.0906) | -0.0962 | (0.0974) |
| September 2001 dummy | | | | | 0.0444 | (0.0889) | 0.0365 | (0.0901) | 0.0264 | (0.0918) |
| December 2001 dummy | | | | | 0.2775*** | (0.1066) | 0.2876*** | (0.1078) | 0.3111*** | (0.1143) |
| March 2002 dummy | | | | | 0.0060 | (0.0969) | -0.0036 | (0.0996) | 0.0317 | (0.1011) |
| June 2002 dummy | | | | | -0.0122 | (0.1083) | -0.0125 | (0.1096) | 0.0051 | (0.1107) |
| Kargi location dummy | | | | | 0.2113 | (0.1443) | 0.2046 | (0.1594) | 0.3616 | (0.2257) |
| Logologo location dummy | | | | | 0.1555 | (0.1354) | 0.1450 | (0.1466) | 0.1991 | (0.2063) |
| North Horr location dummy | | | | | -0.1537 | (0.1422) | -0.2104 | (0.1493) | 0.0776 | (0.2263) |
| Suguta Marmar location dummy | | | | | -0.1729 | (0.1379) | -0.1929 | (0.1527) | -0.0855 | (0.1963) |
| Normalized family size | | | | | | | 0.0282 | (0.0238) | 0.0465* | (0.0247) |
| # adult male | | | | | | | -0.0061 | (0.0320) | -0.0277 | (0.0328) |
| H-hold head dummy (1 if male) | | | | | | | 0.0078 | (0.0686) | 0.0244 | (0.0724) |
| Age hhold head | | | | | | | 0.0040 | (0.0163) | -0.0020 | (0.0168) |
| Age hhold head squared | | | | | | | -0.0000 | (0.0002) | -0.0000 | (0.0002) |
| Head years education | | | | | | | -0.0434 | (0.0417) | -0.0155 | (0.0439) |
| Head years education squared | | | | | | | 0.0022 | (0.0036) | -0.0005 | (0.0038) |
| Crops harvested dummy | | | | | | | | | 0.3420** | (0.1720) |
| Currently have bank account dummy | | | | | | | | | -0.1752* | (0.0977) |
| Concern: pasture for animals | | | | | | | | | -0.0666 | (0.1347) |
| Concern: water for animals | | | | | | | | | -0.0721 | (0.1162) |
| Concern: animal sickness/death | | | | | | | | | 0.0914 | (0.1392) |
| Concern: animal theft/raiding | | | | | | | | | 0.2263 | (0.1438) |
| Concern: Insecurity/violence/fights | | | | | | | | | -0.3156** | (0.1406) |
| Concern: Human sickness | | | | | | | | | -0.1208 | (0.1381) |
| Concern: No buyers for animals | | | | | | | | | 0.0004 | (0.1714) |
| Concern: Low prices for animals | | | | | | | | | 0.2356 | (0.1708) |
| Concern: Not enough food for ppl | | | | | | | | | 0.0950 | (0.1220) |
| Concern: High prices for purchases | | | | | | | | | 0.1788 | (0.1699) |
| Concern: Crops fail | | | | | | | | | 0.2377** | (0.1129) |
| Proportion of largestock in herd | | | | | | | | | -0.0064 | (0.1871) |
| Kids away at school (dummy) | | | | | | | | | 0.0989 | (0.0626) |
| Constant | 1.0524*** | (0.0667) | 1.0147*** | (0.0723) | 0.9992*** | (0.1448) | 0.8092* | (0.4255) | 0.3760 | (0.5152) |
| Observations | 353 | | 304 | | 304 | | 298 | | 298 | |
| R-squared | 0.001 | | 0.002 | | 0.190 | | 0.210 | | 0.281 | |
| r2_a | -0.004233 | | -0.005133 | | 0.1538 | | 0.1533 | | 0.1850 | |
| F | 0.2582 | | 0.2263 | | 5.2364 | | 3.6883 | | 2.9260 | |

Standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Dependent variable: normalized number of movements.

## Time Spent (Herfindahl)

| | (1) | | (2) | | (3) | | (4) | | (5) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Herd size in TLU | -0.0052 | (0.0037) | -0.0063 | (0.0040) | -0.0011 | (0.0042) | -0.0010 | (0.0043) | -0.0016 | (0.0049) |
| Herd size in TLU squared | 0.0001 | (0.0001) | 0.0001 | (0.0001) | 0.0001 | (0.0001) | 0.0001 | (0.0001) | 0.0001 | (0.0001) |
| December 2000 dummy | | | | | -0.1866*** | (0.0442) | -0.1883*** | (0.0448) | -0.1631*** | (0.0446) |
| March 2001 dummy | | | | | -0.2173*** | (0.0508) | -0.2233*** | (0.0512) | -0.2174*** | (0.0518) |
| June 2001 dummy | | | | | -0.2123*** | (0.0477) | -0.2063*** | (0.0479) | -0.2151*** | (0.0505) |
| September 2001 dummy | | | | | -0.0771 | (0.0477) | -0.0736 | (0.0477) | -0.0484 | (0.0476) |
| December 2001 dummy | | | | | -0.0718 | (0.0572) | -0.0686 | (0.0570) | -0.0471 | (0.0592) |
| March 2002 dummy | | | | | -0.1348** | (0.0520) | -0.1278** | (0.0527) | -0.1055** | (0.0524) |
| June 2002 dummy | | | | | -0.2223*** | (0.0581) | -0.2092*** | (0.0580) | -0.1720*** | (0.0574) |
| Kargi location dummy | | | | | -0.0397 | (0.0774) | -0.0544 | (0.0842) | -0.0912 | (0.1170) |
| Logologo location dummy | | | | | 0.0766 | (0.0726) | 0.0598 | (0.0775) | 0.0646 | (0.1069) |
| North Horr location dummy | | | | | -0.0420 | (0.0763) | -0.0154 | (0.0789) | -0.0175 | (0.1174) |
| Suguta Marmar location dummy | | | | | 0.1097 | (0.0740) | 0.1193 | (0.0807) | 0.1136 | (0.1016) |
| Normalized family size | | | | | | | -0.0024 | (0.0126) | -0.0121 | (0.0128) |
| # adult male | | | | | | | 0.0069 | (0.0169) | 0.0211 | (0.0170) |
| H-hold head dummy (1 if male) | | | | | | | -0.0293 | (0.0363) | -0.0172 | (0.0376) |
| Age hhold head | | | | | | | -0.0066 | (0.0086) | -0.0026 | (0.0087) |
| Age hhold head squared | | | | | | | 0.0001 | (0.0001) | 0.0000 | (0.0001) |
| Head years education | | | | | | | 0.0407* | (0.0220) | 0.0426* | (0.0227) |
| Head years education squared | | | | | | | -0.0034* | (0.0019) | -0.0035* | (0.0019) |
| Crops harvested dummy | | | | | | | | | -0.0722 | (0.0891) |
| Currently have bank account dummy | | | | | | | | | 0.0712 | (0.0506) |
| Concern: pasture for animals | | | | | | | | | 0.1668** | (0.0698) |
| Concern: water for animals | | | | | | | | | -0.1932*** | (0.0604) |
| Concern: animal sickness/death | | | | | | | | | -0.0223 | (0.0721) |
| Concern: animal theft/raiding | | | | | | | | | -0.0166 | (0.0745) |
| Concern: Insecurity/violence/fights | | | | | | | | | 0.0014 | (0.0728) |
| Concern: Human sickness | | | | | | | | | 0.0523 | (0.0715) |
| Concern: No buyers for animals | | | | | | | | | 0.0393 | (0.0888) |
| Concern: Low prices for animals | | | | | | | | | -0.1012 | (0.0884) |
| Concern: Not enough food for ppl | | | | | | | | | 0.0467 | (0.0632) |
| Concern: High prices for purchases | | | | | | | | | 0.0823 | (0.0880) |
| Concern: Crops fail | | | | | | | | | 0.0065 | (0.0589) |
| Proportion of largestock in herd | | | | | | | | | -0.1041 | (0.0969) |
| Kids away at school (dummy) | | | | | | | | | 0.0823** | (0.0324) |
| Constant | 0.4063*** | (0.0358) | 0.4245*** | (0.0387) | 0.4799*** | (0.0777) | 0.6024*** | (0.2250) | 0.5167* | (0.2670) |
| Observations | 353 | | 304 | | 304 | | 298 | | 298 | |
| chi2 | 2.0791 | | 2.6981 | | 52.162 | | 57.826 | | 82.042 | |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Dependent variable: TLU-unweighted Herfindahl.

| | (1) | | (2) | | (3) | | (4) | | (5) | |
|---|---|---|---|---|---|---|---|---|---|---|
| Herd size in TLU | -0.0111** | (0.0044) | -0.0110** | (0.0047) | -0.0059 | (0.0049) | -0.0067 | (0.0051) | -0.0151*** | (0.0057) |
| Herd size in TLU squared | 0.0002** | (0.0001) | 0.0002* | (0.0001) | 0.0001 | (0.0001) | 0.0001 | (0.0001) | 0.0003*** | (0.0001) |
| December 2000 dummy | | | | | -0.1004* | (0.0515) | -0.0930* | (0.0522) | -0.0870* | (0.0512) |
| March 2001 dummy | | | | | -0.0924 | (0.0592) | -0.0821 | (0.0598) | -0.0773 | (0.0595) |
| June 2001 dummy | | | | | -0.0838 | (0.0556) | -0.0750 | (0.0559) | -0.0951 | (0.0580) |
| September 2001 dummy | | | | | -0.0227 | (0.0557) | -0.0145 | (0.0557) | 0.0026 | (0.0547) |
| December 2001 dummy | | | | | -0.0129 | (0.0667) | -0.0091 | (0.0665) | -0.0708 | (0.0681) |
| March 2002 dummy | | | | | -0.2801*** | (0.0616) | -0.2771*** | (0.0624) | -0.3229*** | (0.0617) |
| June 2002 dummy | | | | | -0.2490*** | (0.0692) | -0.2429*** | (0.0693) | -0.2539*** | (0.0679) |
| Kargi location dummy | | | | | -0.1163 | (0.0902) | -0.1282 | (0.0985) | -0.1191 | (0.1349) |
| Logologo location dummy | | | | | 0.0659 | (0.0845) | 0.0369 | (0.0905) | 0.2030* | (0.1228) |
| North Horr location dummy | | | | | -0.0240 | (0.0892) | 0.0193 | (0.0924) | 0.1062 | (0.1356) |
| Suguta Marmar location dummy | | | | | 0.0742 | (0.0863) | 0.0512 | (0.0944) | 0.1525 | (0.1167) |
| Normalized family size | | | | | | | 0.0042 | (0.0148) | 0.0005 | (0.0148) |
| # adult male | | | | | | | -0.0105 | (0.0199) | 0.0086 | (0.0197) |
| H-hold head dummy (1 if male) | | | | | | | -0.0126 | (0.0427) | -0.0272 | (0.0436) |
| Age hhold head | | | | | | | -0.0138 | (0.0101) | -0.0067 | (0.0100) |
| Age hhold head squared | | | | | | | 0.0002 | (0.0001) | 0.0001 | (0.0001) |
| Head years education | | | | | | | 0.0175 | (0.0257) | 0.0202 | (0.0261) |
| Head years education squared | | | | | | | -0.0005 | (0.0022) | -0.0004 | (0.0022) |
| Crops harvested dummy | | | | | | | | | 0.2646** | (0.1022) |
| Currently have bank account dummy | | | | | | | | | 0.1540*** | (0.0581) |
| Concern: pasture for animals | | | | | | | | | 0.0691 | (0.0799) |
| Concern: water for animals | | | | | | | | | -0.0165 | (0.0692) |
| Concern: animal sickness/death | | | | | | | | | 0.1329 | (0.0830) |
| Concern: animal theft/raiding | | | | | | | | | -0.0479 | (0.0854) |
| Concern: Insecurity/violence/fights | | | | | | | | | -0.1213 | (0.0835) |
| Concern: Human sickness | | | | | | | | | -0.0539 | (0.0826) |
| Concern: No buyers for animals | | | | | | | | | 0.0795 | (0.1018) |
| Concern: Low prices for animals | | | | | | | | | -0.1698* | (0.1015) |
| Concern: Not enough food for ppl | | | | | | | | | 0.0247 | (0.0726) |
| Concern: High prices for purchases | | | | | | | | | -0.1181 | (0.1008) |
| Concern: Crops fail | | | | | | | | | -0.0516 | (0.0678) |
| Proportion of largestock in herd | | | | | | | | | 0.2364** | (0.1120) |
| Kids away at school (dummy) | | | | | | | | | -0.0156 | (0.0377) |
| Constant | 0.3685*** | (0.0424) | 0.3664*** | (0.0451) | 0.3944*** | (0.0905) | 0.6628** | (0.2635) | 0.4740 | (0.3071) |
| Observations | 353 | | 304 | | 304 | | 298 | | 298 | |
| chi2 | 7.5467 | | 7.8912 | | 53.332 | | 61.421 | | 94.113 | |

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Dependent variable: TLU-weighted Herfindahl.

**Distance Traveled**