

# Valuing Asset Insurance in the Presence of Poverty Traps: A Dynamic Approach

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## Abstract:

Ample evidence exists to suggest that nonlinear asset dynamics can give rise to an environment of poverty traps. When dynamic asset thresholds matter, asset insurance offers great promise for managing risks that vulnerable households face. In this paper, we use dynamic programming techniques to generate an option value measure of welfare gains attributable to asset insurance in this context. In particular, we analyze how insurance influences dynamically optimal behavior near a critical asset threshold. Similar to other studies, we find that households with asset levels near a critical asset threshold will choose low levels of insurance due to a high shadow price of liquidity. However, unlike previous studies, we show that the very presence of a formal insurance market actually encourages greater investment by “threshold” households. This investment comes from the hope of reduced vulnerability that insurance offers in the future. Finally, we use our model to make predictions about the value of index-based livestock insurance (IBLI) in Marsabit district of northern Kenya. Our results suggest that these behavioral changes brought about by insurance may result in decreased poverty levels over time.

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# 1 Introduction

Northern Kenya's arid and semi arid lands are home to more than 3 million pastoralist households who depend primarily on livestock as their main livelihood. The risk of drought renders herds in this area susceptible to significant livestock mortality shocks, resulting in pronounced income and asset shocks to the pastoralist's household. There is growing evidence that such asset shocks can have permanent consequences if asset levels drop below a critical threshold. Index-based insurance products offer great promise for managing climate-related risks that vulnerable households face.

Such index-based risk transfer products have become quite popular in development research, and have the potential to influence poverty dynamics in critical ways. In this paper we analyze how asset levels and a particular index-based insurance product together influence dynamically optimal behavior at or around an asset threshold. In January 2010 the index-based livestock insurance (IBLI) pilot project was launched in Marsabit District of northern Kenya, and approximately 2,000 contracts were purchased. This paper presents a theoretical dynamic demand analysis of index based livestock insurance (IBLI). Dynamic programming techniques are used to generate an option value measure of the welfare gains attributable to the availability of IBLI for individuals with various asset levels. While we restrict our analysis to the context of livestock insurance, the findings can be applied more broadly to asset insurance in a context of asset-based poverty traps.

Vulnerable households should have a higher option value for insurance if it prevents such households from falling into a poverty trap for which there is no escape. This effect of insurance as a safety net against collapse has been demonstrated theoretically by both Chantarat et al. (2010) and Kovacevic and Pflug (2010). However, these two papers fail to consider a second albeit critical behavioral effect of insurance in the presence of poverty traps. As pastoralism becomes less risky on account of insurance, some individuals may choose to invest in higher risk, higher return activities. Ikegami et al. (2011) supplements the Chantarat et al. (2010) study by analyzing the endogenous behavioral effects of IBLI. In a more general study, de Nicola (2011) shows that the welfare gains attributable to weather insurance are in part due to changes in optimal consumption and investment decisions. However, to the authors' knowledge no paper to date has considered the behavioral effects of index insurance while explicitly accounting for poverty traps.

If the optimal investment changes with insurance, then not only are vulnerable households prevented from total collapse, but in addition the asset threshold may shift in such a way that a greater number of individuals are able to reach a higher level asset equilibrium. Such a result contrasts the Chantarat et al. (2010) and Kovacevic and Pflug (2010) studies who both show that households at or just below the asset threshold are vulnerable to collapse if paying the premium pushes them below the asset threshold. If households around the threshold level can gain from insurance, then important implications for development policy become apparent. Furthermore, our model provides testable empirical hypotheses in that we predict demand for asset insurance as a nonlinear function of assets. In this way, our theoretical model lends itself nicely to direct empirical study.

The rest of this paper is structured as follows: Section 2 provides an extensive review of the related literature. To better understand the context we first discuss the importance of risk in a world of poverty traps before discussing the potential benefits of index insurance.

In general, demand for insurance products in developing countries has been much lower than anticipated. When demand is especially low, identifying the factors suppressing demand becomes complicated. Since demand for IBLI in its first year of the pilot was relatively high, we intend to use the theoretical model presented in Section 3 to develop an empirical model for IBLI demand. Furthermore, we can use the model to test empirically for a poverty trap. This theoretical model of demand for asset insurance carefully accounts for asset dynamics and optimal decision making over time in the presence of a structural poverty trap.

Throughout Section 4 we consider the case of mandated permanent insurance, where optimal choice rests in consumption and investment decisions only. Here we can think of the mandated insurance as a household’s “pre-commitment” to a lifetime of full insurance, ruling out any dynamic mixed strategies. In sections 4.1 and 4.2 we provide a discussion of the results of the numerical analysis including the optimal asset accumulation paths over time and a dynamic option value for insurance in this scenario. Our results suggest that the welfare gains from asset insurance for a given household stem from four primary features. First, we find that in the presence of an insurance market fewer herds are vulnerable to collapsing to a low level equilibrium. Second, the the asset level below which households fall to a poverty trap shifts. Third, the average high level equilibrium is substantially higher with insurance. Finally, households are better able to smooth both assets and consumption.

In Section 5 we relax the assumption of permanent insurance, and consider a household’s optimal insurance decision. We find that while trapped households may not choose to purchase insurance, the presence of a permanent insurance market makes increased investment optimal. Our unique contribution stems from recognizing the importance of this behavioral change induced by insurance in altering poverty dynamics.

In Section 6 we then use the empirical herd distribution in Marsabit to consider the implications our model poses for poverty dynamics in northern Kenya. Our results suggest that these behavioral changes brought about by insurance may result in decreased poverty levels over time. Section 7 closes with some concluding remarks.

## 2 Review of the Literature

### 2.1 Poverty Traps and Risk

As economists we often think of the poorest of the poor as being those households who are “trapped” in poverty. The income of these households lies below some poverty threshold, which makes it difficult for them to “pull themselves up by their bootstraps.” Instead, these households remain trapped in their current state unable to reach a higher equilibrium. Bowles, Durlauf and Hoff (2006), and Dercon (2003) provide nice literature reviews of the theory of poverty traps.

One special class of poverty trap requires the existence of multiple dynamic equilibrium, and is characterized by at least one critical threshold above which the expected dynamics of the system lead to positive asset accumulation, and below which the decumulation of assets prevails. For this type of poverty trap, uninsured risk can affect the poor in two distinct ways: *ex ante* and *ex post*. *Ex ante*, poverty traps may induce households to misallocate resources toward activities with lower risk but lower return in order to minimize risk. *Ex*

*post*, a random shock can be catastrophic if it causes significant asset losses which drop the household below the asset threshold, sometimes resulting in malnutrition, children being removed from school, displacement of families and other undesirable effects (Alderman and Haque 2007, Skees and Collier 2008). In a world of substantial asset shocks, a single negative shock can permanently force a household off a positive growth trajectory toward a low level equilibrium (Barrett et al. 2007).

Missing financial markets for both credit and insurance amplify the problem of uncertainty. If financial institutions exist such that people can insure against shocks *ex ante* or borrow *ex post* (thereby achieving quasi-insurance) the undesirable effects of risk can be attenuated. However, missing financial markets are ubiquitous in developing countries, the unfortunate result of poor contract enforcement mechanisms, information asymmetries, high transaction and monitoring costs, and covariate risk exposure (Barnett, Barrett and Skees 2008, Alderman and Haque 2007).

Empirical evidence suggests that the risk of drought renders pastoralist households in East Africa vulnerable to large herd mortality shocks, and therefore large income shocks as well. In addition, because a pastoralist's main livelihood rests in livestock, evidence of nonconvex asset dynamics suggests that this context provides a unique opportunity to study poverty traps. Recent qualitative fieldwork in Marsabit suggests that northern Kenyans can recognize this "poverty trap" phenomenon and many are able to provide examples of households which are trapped by a small and stagnant herd size.

In nearby southern Ethiopia Lybbert et al. (2004) report direct empirical evidence of poverty traps in herd accumulation of pastoralists. Their study shows that after a shock, only one third of households below a certain threshold were able to recover 95% of their losses after three years. This result can be compared to medium size herds which were expected to recover fully and large herds which were expected to recover at least up to a high level equilibrium point. The paper suggests herd dynamics with two asset-based thresholds. Below the lower threshold, herds are expected to have negative growth leading to a low level equilibrium (herd collapse). Above the lower threshold, but below an upper threshold, herds on average show near constant growth. (In this paper, we argue that in a risky environment, these households are vulnerable to collapse.) If herd size is above the upper threshold, then positive growth toward a high level equilibrium is achieved. Sieff (1998) describes similar herd dynamics in a study of Datoga pastoralists in Tanzania.

The driving forces behind the herd dynamics just described are unclear. In the absence of insurance or credit markets, a risky environment may present an incentive for households to use livestock in order to smooth consumption. Dercon (1998) presents a model in which the need for consumption smoothing requires offtake of livestock to buy food during periods of income shortfalls. This also depletes the savings necessary for further investment in livestock. Furthermore, once herds collapse, households are forced into low-risk, low-return production activities which "traps" households at a low level equilibrium. This finding supports a plethora of research that has shown that poor households tend to adopt low-risk, low-return strategies for using productive assets in response to uncertainty. However, an empirical study by Fafchamps et al. (1998) suggests that livestock in the West African semi-arid tropics are not used to smooth consumption as is commonly thought. This is supported by a growing literature suggesting that nonconvex asset dynamics may create incentives to smooth assets rather than consumption. This literature suggests that individuals may choose

against liquidating assets in order to smooth consumption if the alternative is expected to push them below a threshold at which asset dynamics will cause further exogenous asset loss (Zimmerman and Carter 2003, Lybbert and Barrett 2010, Barrett et al. 2006).

Another possible mechanism leading to poverty traps in this situation is the biological capacity of livestock regarding both mortality and birth. For example, Sieff (1998) reports a negative relationship between herd size and mortality. Both Sieff (1998) and Upton (1986) find that households with large herds milk a smaller proportion of the herd and less milk per cow, which puts less stress on the herd potentially resulting in a lower mortality rate for large herds. On the contrary, Lybbert et al. (2004) find that mortality, the dominant regulator of herd size, is an increasing function of herd size.

Dercon (1998) shows that because investment in livestock is discrete, (i.e. livestock investment is a "lumpy" investment) it is harder for the poor to enter into livestock production especially in the absence of credit markets. This could be seen as yet another driving force of poverty trap dynamics. Others have cited the importance of risk aversion in the determination of the apparent poverty trap. While the structural causes remain unclear, empirical evidence suggests that an asset threshold exists, such that some herders are pushed out of pastoralism if they no longer have enough animals upon which to survive. These households must migrate to towns in search of food aid or other ways to make money to support themselves (McPeak and Barrett 2001, Little et al. 2001, Little et al. 2008, Toth 2010).

## 2.2 Benefits of Index-based Risk Transfer Products

The existence of an asset-based poverty trap presents a troubling dimension of dynamic vulnerability for households in this type of environment. Index-based insurance products offer great promise for managing climate-related risks that these vulnerable households face. Such products have the potential to address both the *ex ante* and *ex post* effects of climate risks. First, properly designed insurance contracts should shift the burden of risk avoidance in order to encourage greater investment in activities with higher risk and higher expected payoffs. Second, insurance can act as a safety net, protecting vulnerable households from collapse toward a low level equilibrium (Barrett et al. 2007, Skees and Collier 2008).

Barrett, Carter and Ikegami (2008) use a stochastic dynamic programming model which clearly demonstrates both the *ex ante* and *ex post* effects of more general social protection programs. They show that threshold-targeted social protection programs which account for the poverty trap mechanism may help to eliminate needless poverty by preventing collapse to a low level equilibrium while boosting growth through endogenous asset accumulation and technology adoption.

Index insurance is an example of a social protection program to which the Barrett et al. model applies. It differs from traditional insurance in that the indemnity payments are based on an indicator which is outside the influence of the insured. Such products have many benefits over traditional insurance, including lower transaction costs and fewer asymmetric information problems which eliminate or greatly reduce adverse selection and moral hazard problems. Index insurance contracts are designed to transfer covariate risk from a vulnerable local population into international financial markets (Barnett, Barrett and Skees 2008). This study looks at a particular index-based risk transfer product, index-based livestock insurance (IBLI), (Chantararat et al. 2007, Chantararat et al. 2009b) and assesses its dynamic role in

counteracting uncertainty in the presence of poverty traps in northern Kenya.

We hypothesize that index-insurance should be particularly valuable for households around an asset threshold. Clearly, effective insurance policies should prevent a vulnerable population from catastrophic collapse to a low level equilibrium. Furthermore, the reduction in risk brought about by insurance may stimulate investment in higher return (albeit higher risk) activities (de Nicola 2011). If this happens, we should also see a shift in the poverty threshold. Theoretical evidence suggests that perceptions of asset thresholds can induce a risk response (Lybbert and Barrett 2007 and Lybbert and Barrett 2010). Empirical evidence in support of this theory is also provided in Carter and Lybbert (2010) who demonstrate the existence of an asset threshold in Burkina Faso, which divides asset smoothers from consumption smoothers. Indeed, we might expect dynamically optimizing poor agents to take steps to stabilize their asset portfolio by allowing consumption to vary in the short run (Zimmerman and Carter 2003). By maintaining asset levels (in our case livestock), future income (rather than consumption) is smoothed. Better still, agents just below the poverty threshold may decide to forgo current consumption in the short run in order to improve their asset portfolio if it pushes them over the threshold and onto the higher level equilibrium path. This contrasts to the household's decision in the absence of insurance, where the risk of negative shocks makes such sacrifices seem useless. This endogenous *ex ante* effect may actually cause the implicit poverty threshold, or "Micawber Threshold" below which agents tend toward a poverty trapped low level equilibrium, to shift in a way such that a greater number of households move toward the higher level equilibrium.

Chantarat, Mude, Barrett and Turvey (2010) are among the first in attempting to analyze the value of index insurance in the presence of poverty traps. Using the same context that we study here, they model herd dynamics as a function of various stochastic processes, and simulate wealth/herd dynamics using rich panel and experimental data from the region. They assume the existence of a threshold herd size, above which the herd will expand, and below which the herd will shrink.

Their theoretical model shows that IBLI does little for pastoralists with beginning herd size below a critical threshold. In addition, paying premiums may even accelerate herd collapse. This is because in the case of no indemnity payment, households have given up a valuable portion of their limited income. Alternatively, in the case that an indemnity payment is paid, these households will have insured so few animals that even the indemnity payment is unlikely to be large enough to push them over the threshold. They are, in essence, trapped.

Contrary to our hypothesis, the same study finds mixed results for households near the poverty threshold. Three scenarios are possible for these vulnerable households. In the first scenario, the household pays the premium and the weather turns sour, so an indemnity payout is received and decumulation is averted. The household's welfare is improved, and they are on a positive herd growth trajectory toward a high level equilibrium. In the second scenario, the household makes a payment which drops them below the threshold. If nature provides good weather then no indemnity payment is received and the household is now on a path of decumulation toward the low level equilibrium. If the household is near the threshold but paying the premium doesn't drop them below the threshold then they have the most to gain, because IBLI now provides a safety net against catastrophic collapse.

These findings are similar to a more mathematical treatment of the same question by

Kovacevic and Pflug (2010). Their ruin theoretic approach shows that for households with capital above but near the critical asset threshold, the probability of collapse to a low level equilibrium increases with the introduction of insurance since the premium payments reduce the ability to create growth.

A critical limitation of the Chantarat et al. (2010) and Kovacevic and Pflug (2010) studies is that they both ignore behavioral choice, focusing instead on herd size as a state variable which follows a stochastic path to determine each household’s future welfare path. In doing so, the models ignore the endogenous *ex ante* effect of the risk reduction brought about by insurance. Cai et al. (2010) find empirical evidence of an endogenous *ex ante* effect of insurance in China, where formal insurance increases farmer’s tendency to invest in risky sow production. Alderman and Haque (2007) argue that it “is more a matter of the degree to which behavior is modified rather than if it changes,” suggesting that the Chantarat et al. (2010) and Kovacevic and Pflug (2010) models may be overlooking an important component in the value of insurance.

Ikegami, Barrett and Chantarat (2011) address this limitation by proposing another model of dynamic investment and purchasing decisions for IBLI. Their study looks at how much household intertemporal behavior will change in the presence of IBLI, and then compares welfare levels with and without the availability of IBLI. While explicitly modeling many details of the IBLI contract, the Ikegami et al. study does not account for poverty traps, and as such cannot capture the value associated with a reduction in the vulnerability of collapse to a permanent low-level equilibrium.

This paper makes a unique contribution to the literature by explicitly modeling dynamically optimal behavior on account of IBLI in the presence of poverty traps. This analysis is critical for understanding the total effects of IBLI and other similar products seeking to reduce risk as a poverty alleviation strategy.

### 3 A Dynamic Model of Asset Insurance

In this section we present a household model of asset insurance in the presence of risk and poverty traps. In order to give the theoretical model some context, we consider a particular index insurance contract available to pastoralists in northern Kenya, but note that our results can be applied more generally to other asset insurance products offered in a context where nonlinear asset dynamics apply.

The model assumes a single numeraire good, livestock, which can be insured. Each household has an initial endowment in the form of a livestock herd,  $H_0$ , where the subscript denotes time. In order to aggregate a herd of mixed livestock which is common in this region, we use tropical livestock units (TLU) so that a herd can consist of cattle (1 TLU), camels (1.4 TLU), goats or sheep (.1 TLU each).

Because the problem is dynamic in nature, we begin by modeling herd dynamics over time. In each period herds can experience both growth and loss. Following Dercon (1998) we model the livestock growth function as  $f(H_t)$ , which can be thought of as a livestock production function. More than just growth, this production function encompasses livestock births as well as “flows” such as milk products, which are a primary staple for people in this area. The loss function is modeled as  $m(\theta_{t+1}, \epsilon_{t+1}, H_t)$ . This mortality function depends

on both a random aggregate shock ( $\theta_{t+1}$ ) which is the same for all households, and an idiosyncratic shock ( $\epsilon_{t+1}$ ) specific to the household's own herd. Both shocks are stochastic, exogenous, and realized for all households after decision-making in the current period, and before decision-making in the next period occurs. In other words, the relevant mortality is unknown whenever a household's decisions are to be made.

We assume a simple structure for the mortality function, such that either shock can be interpreted as proportional herd loss, and  $m(\theta_{t+1}, \epsilon_{t+1}, H_t)$  is simply a linear function of each shock multiplied by herd size:

$$m(\theta_{t+1}, \epsilon_{t+1}, H_t) = \theta_{t+1}H_t + \epsilon_{t+1}H_t \quad (1)$$

Households face a tradeoff between consumption today and investing in the herd for future consumption. The tradeoff is particularly stark in our model since credit markets are assumed to be absent. Assuming a lack of available credit markets implies that consumption must not be greater than the current herd and its flows. That is:

$$c_t \leq H_t + f(H_t) \quad (2)$$

It is also straightforward to impose a non-negativity constraint on herd size at any time  $t$ :

$$H_t \geq 0 \quad (3)$$

Under these assumptions, and in the absence of formal insurance, herd dynamics are captured by the following equation of motion:

$$H_{t+1} = H_t + f(H_t) - c_t - m(\theta_{t+1}, \epsilon_{t+1}, H_t) \quad (4)$$

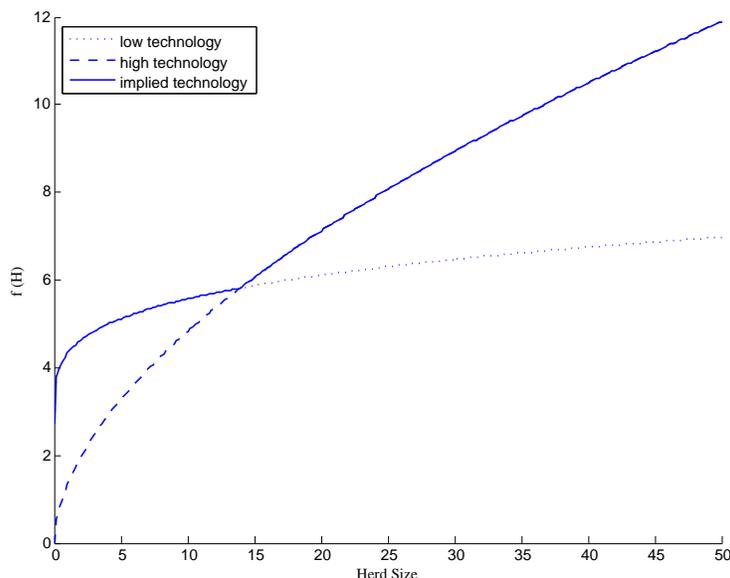
The tradeoff is captured in this: a household can consume all the “growth” in a given period, but then the herd will be smaller in the next period whenever mortality is greater than zero. Similarly, the household can consume more than the flows. Divestment occurs if the household consumes all the flows and part of the herd. Whatever portion of the flows is leftover after consumption can be thought of as an investment back into the herd.

It has been shown that herd dynamics seem to follow a particular growth path where growth is negative if a herd falls below a certain threshold (i.e. if  $H_t \leq \underline{H}$ ), growth is approximately constant for medium levels of herd size (i.e. for  $\underline{H} < H_t \leq \bar{H}$ ), and then positive growth is observed for large levels of herd size (i.e. for  $H_t > \bar{H}$ ) (see Lybbert et al. 2004, Santos and Barrett 2011, and Sieff 1998). To capture these dynamics we allow households to choose between two different production technologies: a low return and a high return technology. The low return technology is analogous in this context to sedentarism, whereas the high return technology can be thought of as the more productive pastoralist production technology. Pastoralism offers higher returns because livestock are brought to better pastures, whereas in sedentarism livestock are constrained to lower quality forage close to the village.<sup>1</sup>

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<sup>1</sup>Toth (2010) offers some evidence that the incentive to engage in mobile pastoralism determines whether a household will become trapped; he posits that households who optimally choose a sedentary lifestyle will fall into a poverty trap whereas those who optimally choose a mobile herding lifestyle will remain above a poverty threshold. We follow the same logic, though the focus of this paper is not why the poverty trap exists.

Figure 1: Livestock Production Technologies



With sedentarism, we assume that households are able to supplement their incomes with petty trade in the village (for example by selling milk or handicrafts) or by collecting food aid. This supplemental fixed income is denoted as  $\underline{f}$ . It can also be interpreted as the transaction costs of pastoralism saved by choosing the low technology. Equation ?? below thus defines the structural form assumed for the production technologies:

$$f(H_t) = \begin{cases} \alpha_L H_t^{\gamma_L} + \underline{f} & \text{if } H_t \leq \hat{H} \\ \alpha_H H_t^{\gamma_H} & \text{if } H_t > \hat{H} \end{cases} \quad (5)$$

where  $0 < \gamma_L < \gamma_H < 1$ . Figure 1 shows the general shape of  $f(H_t)$  under the assumptions set forth. Note that households with smaller herd sizes will optimally choose sedentarism whereas households with larger herds will choose pastoralism. This feature creates nonconvexities in the implicit production function (defined by the outer envelope of the two production technologies). These nonconvexities coupled with borrowing constraints and risk drive the poverty trap mechanisms.

We can now specify the household's objective function in the absence of a working insurance market. The household is assumed to be risk averse and will maximize the expected present discounted value of consumption by choosing consumption for each time period, with expected utility at time  $t$  denoted as  $u_t$ . Implicitly, the household is also deciding how much to invest back in the herd for future benefits. We assume the standard constant relative risk

aversion (CRRA) utility function where  $\rho$  is the coefficient of relative risk aversion:<sup>2</sup>

$$u_t(c_t) = \frac{c_t^{1-\rho} - 1}{1 - \rho} \quad (6)$$

In the absence of insurance or credit markets, the household's optimization problem is characterized by the standard Bellman Equation. We consider the simple case where the shocks are distributed i.i.d., so that the most recent shock, either covariate or idiosyncratic, does not give any information about the next period's shock. In this case, there is only one state variable,  $H$ .<sup>3</sup> Under these assumptions, the problem can be expressed as follows:

$$V(H) = \max_{c>0} u(c) + \beta E_{\theta', \epsilon'} [V(H'|c, H)] \quad (7)$$

subject to the equation of motion for herd dynamics (Equation 4), the budget constraint (Equation 2) and the non-negativity constraint on herds (Equation 3) where  $\beta$  is the time discount rate and the expectation depends on beliefs about the structure of shocks  $\theta$  and  $\epsilon$ .

Let us now suppose households are given the opportunity to insure their livestock. If the household wants insurance, it must pay a premium equal to the price of insurance ( $p$ ) times the number of TLU insured ( $I_t$ ). In theory, the household can choose how many livestock to insure, but it should not be allowed to insure more livestock than it owns. That is, the number of tropical livestock units (TLU) insured for the next season must be less than or equal to the current period herd size:<sup>4</sup>

$$I_t \leq H_t \quad (8)$$

Because of the rapid expansion and development of index insurance contracts in developing countries, we consider index insurance rather than traditional insurance. The basic index insurance contract specifies that an indemnity payout will be made if the index exceeds a certain strike point ( $s$ ). If the index is such that a payout is made, then the household also receives the indemnity payment ( $\delta$ ) for each livestock unit insured. In this way, the indemnity payment can be written as:

$$\delta = \max((i(\theta) - s), 0) \quad (9)$$

Note that  $s$  is known by the household in advance of the decision and assumed to be constant over time for this problem.

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<sup>2</sup>We could also use the alternative and perhaps more common CRRA utility functional form:  $u_t(c_t) = \frac{c_t^{1-\rho}}{1-\rho}$  which yields identical policy functions to the ones derived using Equation 6. However, because we use the value function to derive a dynamic option value we choose instead the more intuitive functional form outlined in Equation 6 because it restricts utility to be positive.

<sup>3</sup>If instead the shocks are serially correlated, the agent would use the most recent shock to forecast future herd size. The state space would then include current and maybe past realizations of  $\theta$  and  $\epsilon$  in addition to  $H$ . While this may more closely reflect reality, doing so only clouds our understanding of the mechanisms at work in this particular problem.

<sup>4</sup>Note that in practice this constraint is extremely difficult to enforce, and preliminary empirical evidence suggests that this constraint is not binding. Alderman and Haque (2007) point out that laborers and merchants whose incomes are indirectly linked to (livestock) production could, in principal, choose to purchase insurance at a level commensurate with the laborer's perceived exposure to a given shock.

The household's decision today is whether or not to insure the herd against future loss. Timing is critical here. When the household chooses consumption and how much insurance to purchase, they don't know what kind of mortality their herd is about to experience. This also means households don't know in advance if the insurance index  $i$  will cause the insurance to pay out before moving to the new period. This risk enters through the random covariate shock  $\theta_{t+1}$  which is realized for all households after optimal choices have been made. Hence,  $\delta$  can be written as a function of the index  $i$  which depends on  $\theta$ .

A notable feature of index insurance is that the insurance contract and indemnity payments are based on an aggregate index, rather than individual outcomes, a feature made clear by the definition of  $\delta$ . In this case, both the mortality function and the index depend on the covariate shock. While they are positively correlated, they need not be perfectly correlated. The difference between individual livestock mortality and the index (which can be thought of as predicted livestock mortality) represents basis risk. Hence, risk enters the problem in three related ways: the covariate shock  $\theta_t$ , the idiosyncratic shock  $\epsilon_t$ , and basis risk ( $i(\theta_t) - m(\theta_t, \epsilon_t, H_t)$ ). To simplify the problem we assume the index perfectly predicts the covariate shock, so that  $i(\theta) = \theta$ . In this case basis risk is simply captured by  $\epsilon$ .<sup>5</sup>

We can now rewrite the Bellman Equation to reflect the additional choice variable,  $I$ .

$$V(H) = \max_{c>0, 0 \leq I \leq H} u(c) + \beta E_{\theta', \epsilon'} [V(H'|c, I, H)] \quad (10)$$

The solution is restricted by the non-negativity constraints on  $H'$  (Equation 3), the equation of motion for herd dynamics (Equation 11 below) and the budget constraint (Equation 12 below). The latter two are revised as follows to reflect the available insurance market:

$$H' = H + f(H) - c - pI - m(\theta', \epsilon', H) + \delta(i(\theta'))I \quad (11)$$

$$c + pI \leq H + f(H) \quad (12)$$

The solution to this problem finds the optimal consumption, insurance and investment decisions in each year. In order to solve the problem using numerical methods, we first assume a heterogenous population with identical preferences and uniformly distributed initial asset levels. In Section 6 we extend the analysis to consider the dynamic implications our findings hold for the observed empirical distribution of asset levels.

In order to realistically reflect the risky environment that pastoralists find themselves in, the parameters used for the numerical analysis must be calibrated to data collected in the local setting. We use a rough discretization of the estimated empirical distribution of livestock mortality in northern Kenya reported in Chantarat et al. (2011) to establish a vector of covariate shocks. Since mortality rates have been shown by the same study to be highly correlated within the geographical clusters upon which the index is based, we assume relatively small idiosyncratic shocks. Using the empirically-derived discretization allows expected mortality to be 8.46% with the frequency of events exceeding 10% mortality an approximately one in three year event. These two features both reflect observed mortality characteristics in the region.

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<sup>5</sup>One possible extension is to relax this assumption to better understand how basis risk affects insurance demand by households affected by a poverty trap threshold. We leave this to future analysis.

From the distribution of covariate shocks we calculate the actuarially fair premium using the same strike point as is found in the actual IBLI contract. Parameters for the utility function ( $\rho$  and  $\beta$ ) are specified using plausible values known from economic theory, and then subjecting the model to specification tests.

The production function has been specified to follow the dynamics outlined in the model. Rather than explicitly calibrating the parameters of the production function based on empirical data (which may be impossible), we instead use general knowledge about the dynamics of the pastoral system in this region based on Lybbert et al. 2004 and Santos and Barrett 2011. This quasi-calibration allows us to set the threshold and equilibrium levels approximately where they have been shown to exist. The link between non-linear asset dynamics and the production technology is made complete by the empirically-derived distribution of the shocks. The parameters used to solve the dynamic programming problem are reported in Table 1.

The solution to the problem can be found by solving a stochastic dynamic programming problem. We use value function iteration, by which it follows that the Bellman equation has a unique fixed point as long as Blackwell’s Sufficient Conditions (monotonicity and discounting) are satisfied. Notice that the timing of events is as follows:

1. In period  $t$  households choose optimal  $c_t$ ,  $I_t$  and (implicitly)  $i_t$  based on state variable  $H_t$  and the expectation of future livestock mortality and insurance payout.
2. Households observe exogenous shocks  $\theta_{t+1}$  and  $\epsilon_{t+1}$  which determine livestock mortality  $m(\theta_{t+1}, \epsilon_{t+1}, H_t)$  and insurance payout  $\delta(i(\theta_{t+1}))$ .
3. These functions,  $m(\theta_{t+1}, \epsilon_{t+1}, H_t)$  and  $\delta(i(\theta_{t+1}))$ , together with the optimal choices from period  $t$  determine  $H_{t+1}$  through the equation of motion for herd dynamics (Equation 11).
4. In period  $t + 1$  households choose optimal  $c_{t+1}$ ,  $I_{t+1}$  and (implicitly)  $i_{t+1}$  based on the newly updated state variable  $H_{t+1}$  and the expectation of future livestock mortality and indemnity payment...

The critical timing assumption is that the shocks happen post-decision and determine  $H_{t+1}$  given your choices of  $c_{t+1}$ ,  $I_{t+1}$  and  $i_{t+1}$ , and then once again all the information needed to make the next period’s optimal decision is contained in  $H_{t+1}$ .

We conduct the analysis by comparing three cases. First, by applying the value function iteration method to the Bellman Equation of the agent’s decision problem, we derive the optimal consumption and (herd) investment decisions in the absence of an insurance market. We then consider a case where insurance is permanently mandated (i.e. where a government mandates full insurance in perpetuity). This situation can be thought of as a “pre-commitment” to a lifetime of full actuarially fair insurance. Comparing this situation to an autarkic environment where no formal insurance market exists provides useful insights into the value of insurance. The results of the “pre-commitment” insurance case are presented in Section 4. In Section 5 we relax the assumption of mandated insurance and consider the more realistic case where individuals can choose in every period whether or not they would like to purchase an annual insurance contract.

Comparing the value functions defined by the optimal consumption and investment decisions with and without insurance provides a way to measure the value of the insurance market to the pastoralist. More specifically, we generate a dynamic option value measure of the value of IBLI for heterogeneous households which can be used for welfare analysis. Zimmerman and Carter (1999) provide an example of this approach. They create a household-specific dynamic option value measure for marketable property rights in West Africa. They recognize that the value function of the dynamic programming model contains important information about the utility value of a particular institutional environment for individual agents. They capture this utility value in the form of the option value. Through dynamic stochastic programming they are able to model agent heterogeneity in demand for institutional change while accounting for dynamic rationality and dynamic adaptation to institutional change.

In this case, we can denote  $V_{NI}^*$  as the value function in the absence of an insurance market and  $V_I^*$  as the value function when insurance is available. Following Zimmerman and Carter (1999), the dynamic option value  $z^+(H)$  is then defined as the certain consumption transfer that would just make the constrained (no insurance) value function equal to the unconstrained (with insurance) value function. Formally:

$$V_I^*(H) = V_{NI}^*(H + z^+(H)) \quad (13)$$

Solving for  $z^+(H)$  yields the welfare gains from the presence of an insurance market. Similarly, the option value can be thought of as the amount that must be taken from the unconstrained household in order to make them equally as well off as the constrained household. This is written as  $z^-(H)$  in the following:

$$V_I^*(H - z^-(H)) = V_{NI}^*(H) \quad (14)$$

Note that equation  $z^+(H)$  is essentially a compensating variation measure of welfare gains whereas  $z^-(H)$  corresponds to the equivalent variation interpretation.

An important hypothesis we wish to analyze is whether vulnerable households near a poverty threshold will have a higher option value for insurance. If IBLI prevents such households from falling into a poverty trap from which there is no escape, then we expect they will value it highly. Second, we expect that the presence of an active insurance market will influence dynamically optimal behavior at or around a poverty threshold. This endogenous effect may cause the effective poverty threshold to shift, allowing a greater number of households to reach the high level equilibrium. These factors combined will be reflected in the dynamic option value.

## 4 The Case of Pre-Commitment Lifetime Insurance

### 4.1 Optimal Herd Accumulation

Solving the dynamic optimization problem in Equation 10 derives policy functions for individuals with heterogeneous asset levels. It can be useful to simulate the optimal consumption and investment decisions for agents who are subjected to a series of shocks. This allows us to

investigate herd dynamics in various settings. We show four primary impacts of actuarially fair insurance on dynamic asset accumulation in this section:

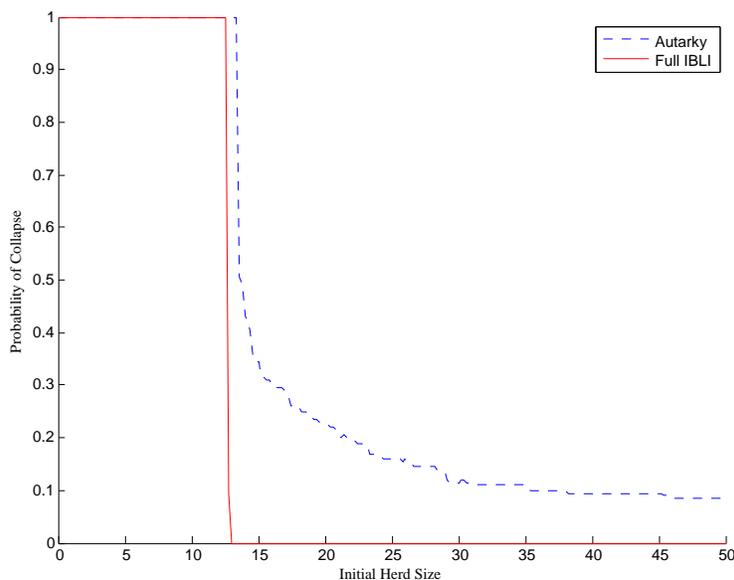
1. **Vulnerability Effect:** Insurance acts as a safety net, offering a reduction in the vulnerability of collapse to the low level equilibrium.
2. **Smoothing Effect:** The path to accumulation involves fewer ups and downs; it is smoother.
3. **Shifting Equilibrium Effect:** An insured herd is likely to reach a higher terminal herd size regardless of initial endowment than its uninsured counterpart.
4. **Shifting Threshold Effect:** The relevant asset threshold below which households collapse to a low level equilibrium is reduced. That is, when assets can be insured, fewer assets are necessary to have a positive probability of reaching the high equilibrium.

As we would expect, relative to an uninsured population, a much smaller proportion of the population can be identified as vulnerable (likely to fall to a low equilibrium) when households are insured for a lifetime. This “vulnerability effect” of insurance is most clearly depicted in figure 2 which shows the probability of arriving at a low level equilibrium with and without insurance. Because of the assumption of nonconvexities in the production technology (from which we observe a poverty trap), the probability of approaching the low level equilibrium is 100% for herds that are already below a critical asset threshold. In a sense these households have already collapsed and have no prospects of escape; they are “trapped”. This asset threshold, which appears to be around 13.5 TLU, is commonly referred to in the literature as the Micawber threshold. Notice that because most households below the Micawber threshold do not experience any change in the probability of arriving at a low level asset equilibrium (because they are essentially trapped with or without insurance), other than those very near the threshold, these households also do not gain via the vulnerability effect.

The truly vulnerable population is that which has a positive, but less than 100% chance of falling to the low level equilibrium, where a higher probability of collapse indicates greater vulnerability. These households are not trapped, but are at risk of experiencing asset collapse which could send them into a trap. As we would expect, the presence of insurance sharply reduces the number of households which can be classified as vulnerable by this definition. The vulnerability effect is largest for households with asset levels between 13 and 20 TLU who experience a 20% to 100% reduction in vulnerability. Some of these households shift from near 100% probability of collapse to having the ability to reach the high equilibrium with the same probability. Others go from extreme vulnerability to 100% protection against catastrophic losses which would otherwise result in a poverty trap. These households seem to benefit greatly from this vulnerability effect.

As asset levels increase, households autarkic vulnerability also decreases, and therefore the reduction in vulnerability decreases. Note that in the absence of an insurance market the probability of collapse remains positive even for large herd sizes. This is in sharp contrast to the case of insured livestock, where the probability of collapse falls to zero once they reach a critical herd size threshold of approximately 13. In addition, the critical herd size at

Figure 2: Probability of Collapse to a low level equilibrium with and without IBLI



which herds appear to collapse with probability near 100% actually decreases slightly when insurance is present. Where it would take at least 13.5 TLU to have a chance of reaching the high equilibrium in autarky, insured households with 13 TLU are able to escape the poverty trap. This is our first indication that the relevant threshold changes when an active insurance market is introduced.

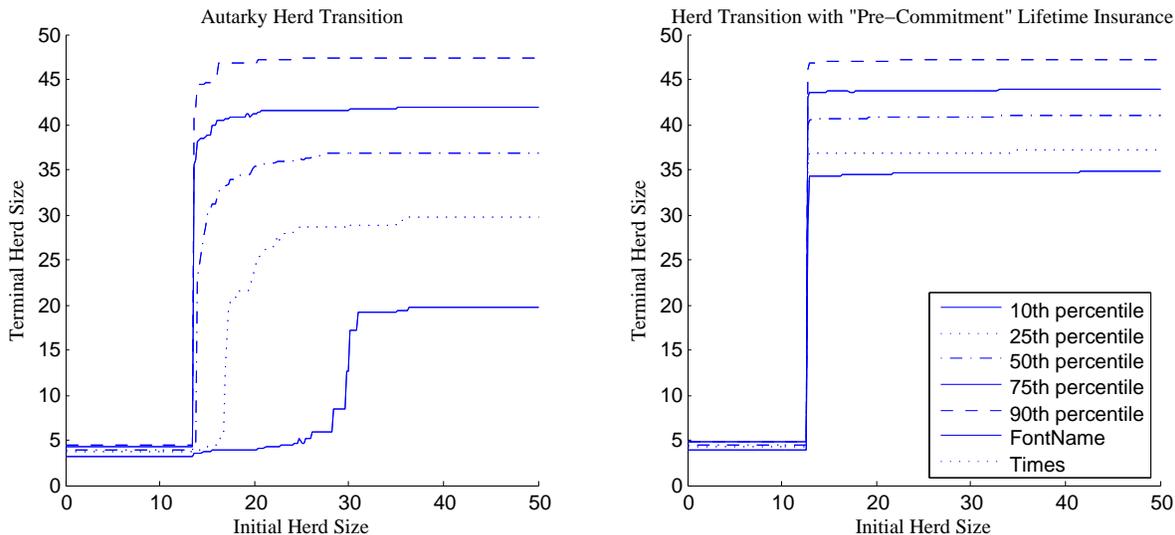
The next thing we expect to see is a reduction in the variability of outcomes when households become permanently insured. This is the “smoothing effect” of insurance. This effect is captured by figure 3 which plots the 10th, 25th, 50th, 75th and 90th percentiles of the terminal herd size across simulations as a function of initial herd size under autarky and with IBLI. For a given initial herd size, the similarity of the 10th percentile to the 90th percentile (across simulations) is an indicator of low variability across outcomes. In figure 3 we see that the 90th percentile more closely matches the 10th percentile when insurance is available than in autarky. This provides some evidence of a smoothing effect.

In addition to the smoothing effect, figure 3 also suggests a “shifting equilibrium effect” induced by permanent insurance. A cursory glance at the median terminal herd size shows a distinctly elevated high level equilibrium. Another avenue through which we observe this shifting equilibrium effect is by analyzing the mean herd accumulation paths over a large number of simulations for heterogeneous levels of initial herd size under autarky and with permanent full insurance.<sup>6</sup> We show these average herd accumulation paths in figures 4 and 5.

Based on the assumptions set forth by the model, uninsured households have a hard time accumulating herds greater than 34 TLU. This is in contrast to the average high level equilibrium attainable with insurance: 40+ TLU after 50 years. That’s a difference of more

<sup>6</sup>We take mean and median herd size over simulations for each initial herd size and each  $t$ .

Figure 3: Herd Transition: Initial to Terminal



than 6 cattle per household, a greater than 17% increase. This higher level is reached because the effect of negative shocks is reduced.

Initial endowment clearly matters in both scenarios, and households with a larger initial endowment are likely to end up at a higher herd size in the final period. However, there is a high level of variation observed in the autarky case, especially for those with initial herd size above 13.5 TLU. The high variability of terminal herd size for households with an initial herd size between 13.5 and 17.5 (or more) TLU points again to a high level of vulnerability for these uninsured households (vulnerability here again refers to a high probability of collapsing to a low level equilibrium). Moreover, uninsured households with an initial endowment below 13.5 TLU appear, at least on average, to have low growth prospects, settling into a low level equilibrium around 4 TLU. When households “pre-commit” to a lifetime of full insurance the average path for those with less than 12.7 TLU is still movement toward a low level equilibrium, though the ending herd size of 4.8 TLU after 50 years is somewhat higher than the autarky low-level equilibrium. Through this we observe evidence of a shifting equilibrium effect at both the high and low equilibrium levels. This effect is likely a repercussion of the smoothing and vulnerability effects.

The key implication here is that the mean initial herd threshold level for divergence toward the low level equilibrium shifts downward for insured households, implying that more households are able to achieve positive herd growth. Specifically, the probable path for households with assets between 12.7 and 13.5 TLU is dramatically altered when insurance is introduced. This “shifting threshold effect” seems to imply that insurance would be highly valuable to individuals with 12.7 to 13.5 TLU because they are suddenly able to achieve positive growth with greater than 50% probability when they insure their herd.

The shifting threshold effect is perhaps more discernible if we return to figure 3 and focus on the median under both scenarios. If we consider the median to be a representative household, it should be clear to the reader that households beginning with approximately 13-

Figure 4: Mean herd accumulation paths for various initial herd sizes

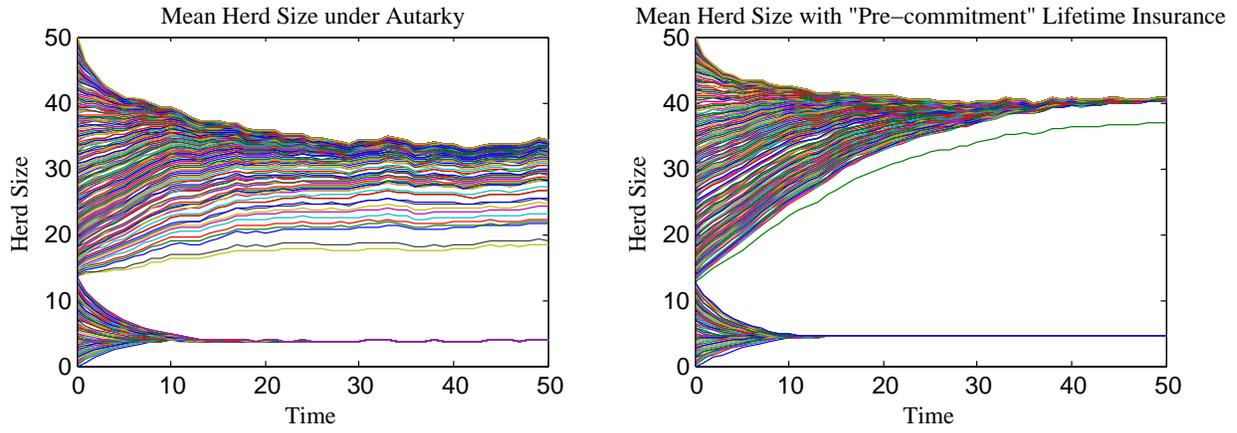


Figure 5: Mean herd accumulation paths: Closer look at asset thresholds

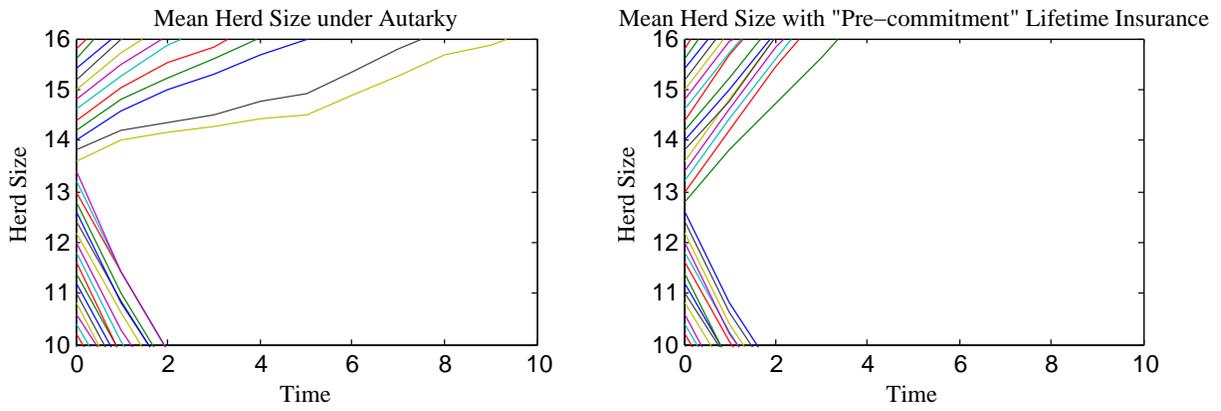
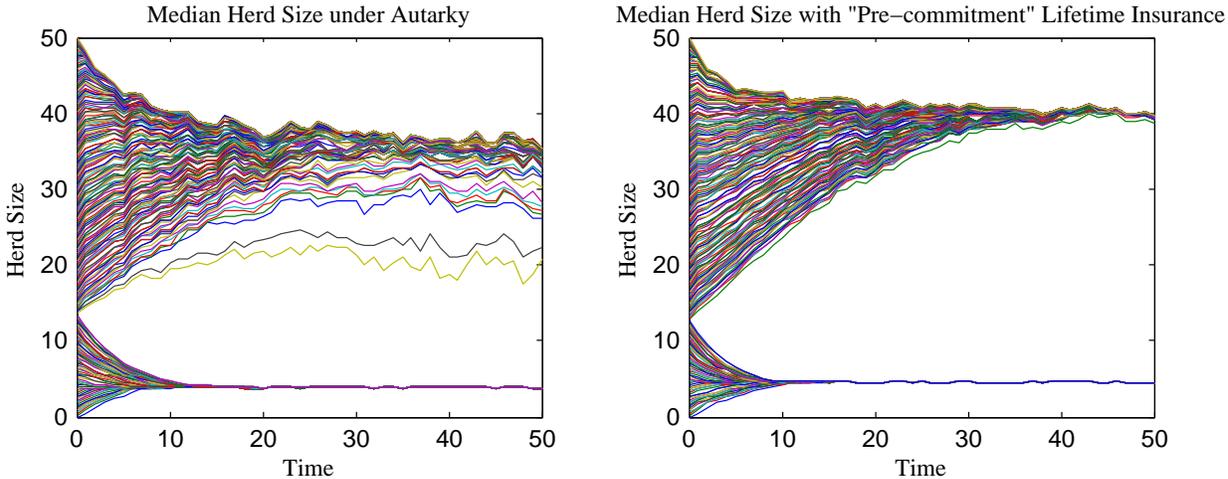


Figure 6: Median herd accumulation paths for various initial herd sizes



13.5 TLU are able to achieve a much higher terminal herd size with insurance than without. In this way we see that the Micawber threshold (initial asset level necessary to achieve the high equilibrium) appears to shift from 13 to 13.5 TLU. Once again, we would therefore expect households in this asset range to benefit greatly from insurance!

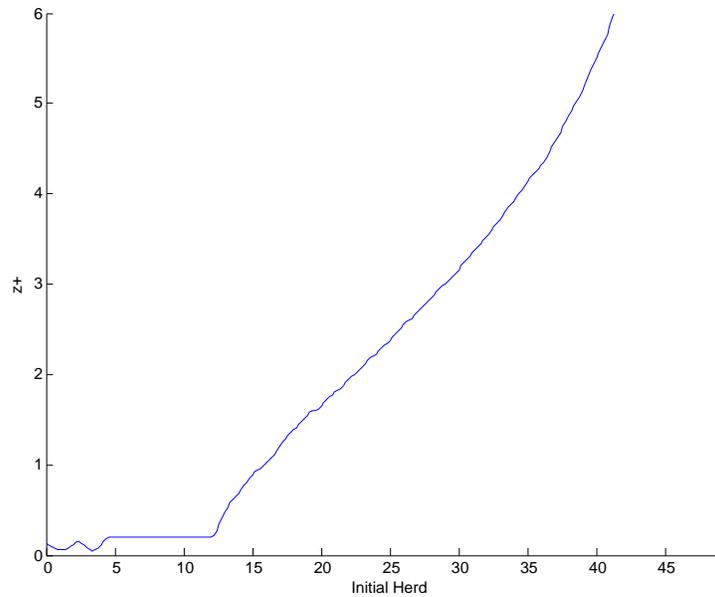
One final way to ascertain how an insurance market affects the population is to consider the median paths in greater detail. In contrast to the *average* herd accumulation paths observed in figures 4 and 5, figure 6 plots the *median* herd accumulation paths over a large number of simulations for heterogeneous levels of herd size with and without insurance. Once again, these paths demonstrate the extreme vulnerability faced by households in the absence of a working insurance market. Notice that in the autarky case a few seasons of bad shocks can be path altering if it drops households to the low level equilibrium. These paths seem to provide further evidence of all four effects discussed thus far: vulnerability effect, smoothing effect, shifting equilibrium effect, and shifting threshold effect.

By explicitly modeling insurance in the presence of poverty traps, our model provides evidence that the value of insurance depends not only on the commonly considered vulnerability and smoothing effects, but also a shift in equilibrium and threshold levels. These four effects combined will reflect how households value insurance. In particular, the potentially path-altering impacts characterized by the vulnerability and shifting threshold effect may result in a greater willingness to pay for households around the Micawber threshold. The next section expands on this topic.

## 4.2 The Value of Insurance

We are now ready to compare the value of insurance for households under autarky and in the presence of perfect lifetime insurance. As discussed earlier, to do this we can construct a dynamic option value. Here we consider the option value  $z^+(H)$  outlined in Equation 13, that is: the average amount that must be given to an uninsured household to make them

Figure 7: Dynamic Option Value



equally as well off as an insured household. The alternative option value outlined in Equation 14 provides a nearly identical interpretation and is left out in the interest of brevity. Figure 7 plots the option value as a function of herd size.

Using this measure of a dynamic option value we see that the value of insurance is increasing in assets, with a jump around the Micawber threshold. At this point herds destined (on average) for the low level equilibrium in autarky suddenly have a chance of reaching the high level asset equilibrium. The high value for these households should come from exiting out of a poverty trap. This is the value that comes, in particular, from the shifting equilibrium effect, where the Micawber threshold actually shifts from approximately 13.5 TLU in autarky to 12.5 with insurance. Not only that, these households also experience protection against future collapse. These households benefit from the vulnerability effect more than any other household along the asset spectrum.

The magnitude of the option value carries with it some meaning. The option value  $z^+(H)$  is expressed in units of TLU. Figure 7 shows that households with larger asset levels have much to gain from insurance, indeed they have much to lose without it. In the previous section we showed that these households can move more safely and smoothly toward an improved high level equilibrium (about 6 TLU higher) when insurance is present. Such households benefit from the vulnerability, shifting equilibrium and smoothing effects. The value to households at the insured high equilibrium is about 5 cattle. For households below the threshold the value is less than 1 TLU, with households around the low level equilibrium valuing insurance at about 2 goats.

The problem with this measure, which will soon become evident as we study the policy functions, is that households in the range of the Micawber threshold have a high shadow price of liquidity. We know that a small change in assets around the Micawber threshold

can have path-altering implications. For example, giving 1 TLU to a household just below the threshold allows them to escape the poverty trap, completely altering their dynamic path. On the contrary, taking 1 TLU from a household just above the threshold drops the household asset level below the threshold toward ultimate herd collapse. This means the shadow price of liquidity, and assets, are relatively high for “Micawber” households.

This high shadow price of liquidity is reflected in the option value in two ways. First, the marginal benefit of an additional asset varies across asset space, and is particularly high for households holding a level of assets near the Micawber threshold. This can be problematic when using assets as a unit of valuation in constructing the option value. Fewer assets are needed to lift an uninsured household’s utility to the level of an insured household’s utility if the marginal benefit of each asset is higher in this range than at other points along the asset spectrum.

Second, a high shadow price of liquidity means the marginal cost of insurance is also relatively high near the Micawber threshold. This means that even if insurance is largely beneficial to these households, they may still be better off investing in additional assets in an effort to move away from the threshold. Optimal behavior, and thereby utility, is determined not solely by the benefits of insurance, but by the *marginal* benefit of insurance as it relates to the *marginal* benefits of consumption and investing. We explore this further in the remaining sections as we consider the optimal policy functions for consumption, investment and insurance.

In the next section we relax the assumption of pre-committing to a lifetime of insurance and instead allow individuals to choose whether or not they will purchase insurance in any given year. In doing so, we shift the analysis from looking at the benefits of insurance, to considering *marginal* benefits. This also allows us to create a formal measure of willingness to pay which can help to answer the relevant question of who will exhibit positive demand for insurance.

## 5 The Case of an Annual Insurance Decision

It may not be optimal to perpetually insure, as in the case considered in the previous section. Moreover, it may not always be optimal to insure the whole herd, even when it is optimal to insure part of the herd. If choosing to insure isn’t optimal in a given period, it is still possible for a household to dynamically benefit from insurance. This is true if the presence of an insurance market alters a household’s optimal decision for consumption and investment based on expectations about the future. To address these issues, we once again solve the household’s optimal decision problem, this time allowing households to choose consumption, investment, and whether or not they would like to purchase an annual insurance contract. In this first subsection we limit the insurance choice set to zero or full insurance in order to derive a willingness to pay measure for insurance. We then relax the restriction of  $I_t = [0, 1]$  in Section 5.2, where we consider optimal decisions when given the option of partially insuring the herd.

## 5.1 Willingness to Pay for Full Insurance

In order to construct a formal measure of a household's willingness to pay for insurance, we iterate over optimal insurance purchase decisions for a vector of mark up rates on the actuarially fair insurance premium. This allows us to clearly see for whom it is optimal to buy insurance at various prices. For simplicity, we assume that the insurance decision  $I_t$  is binary, where 1 equals full insurance and 0 implies no insurance. That is,  $I_t = [0, 1]$ .<sup>7</sup> We then denote the value function when choosing to fully insure at time  $t$  as  $V(H_t; I_t = 1)$ , and the value without insurance as  $V(H_t; I_t = 0)$ . Because we are iterating over different prices, we add a mark up rate to the value function to express the price of insurance whenever the household purchases insurance. Denoting the mark up rate on the actuarially fair insurance premium  $p$  by  $\lambda$ , we define the willingness to pay for an agent with a herd size of  $H_t$  as the amount,  $(1 + \bar{\lambda})p$  which satisfies the following:

$$V(H_t, \lambda; I_t = 1) \geq V(H_t; I_t = 0) \quad \text{for all } \lambda \leq \bar{\lambda} \quad (15)$$

$$V(H_t, \lambda; I_t = 1) < V(H_t; I_t = 0) \quad \text{for all } \lambda > \bar{\lambda} \quad (16)$$

We compute  $\bar{\lambda}$  as follows. First, we discretize  $\lambda$  into  $\{-0.4, -0.3, \dots, 0.6\}$ . Second, for each value of  $\lambda$ , we compute the optimal consumption, investment and insurance purchase decisions for all possible levels of the state variable,  $H$ . Third, for each value of the state variable, we search the value of  $\bar{\lambda}$  at which the agent switches the optimal insurance purchase decision and thus conditions (15) and (16) hold.

Figure 8 shows  $\bar{\lambda}(H_t)$  using a smoother. We observe a willingness to pay that is greater than the actuarially fair price for households safely above the Micawber threshold, and approximately equal to the actuarially fair price for households below the threshold. However, households in the neighborhood of the Micawber threshold prefer no insurance to full insurance (keeping in mind that partial insurance is still not an option). Why? Threshold households have a high shadow price of liquidity. While our analysis seems to show that threshold households stand to benefit largely from both the threshold and shifting equilibrium effects of insurance, it seems that the cost of full insurance is too much for households when the shadow price of liquidity is so high.

It should be noted that we are not the first to demonstrate that Micawber households may not want to purchase insurance. The same result has been previously captured in the theoretical models put forth by Chantarat et al. (2010) and Kovacevic and Pflug (2010), both of which suggest that paying the premium can send households below the threshold, making them worse off. This is especially true when the marginal benefit of investing is high.

While informative, these results do not necessarily imply that threshold households are unaffected by insurance, especially given the path-altering implications that insurance offers to these same households. In fact, it's quite possible that full insurance may not be optimal, whereas partial insurance is, a question we address in the section that follows.

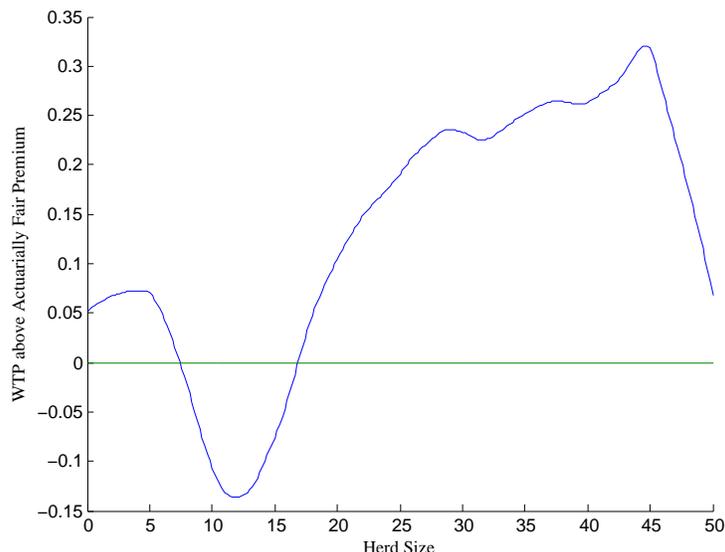
## 5.2 The Partial Insurance Decision

In reality, households are given the option of insuring not only the whole herd, but any fraction of the herd. To replicate reality as closely as our model allows, we discretize insurance

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<sup>7</sup>This assumption is relaxed in Section 5.2.

Figure 8: Willingness to Pay for IBLI



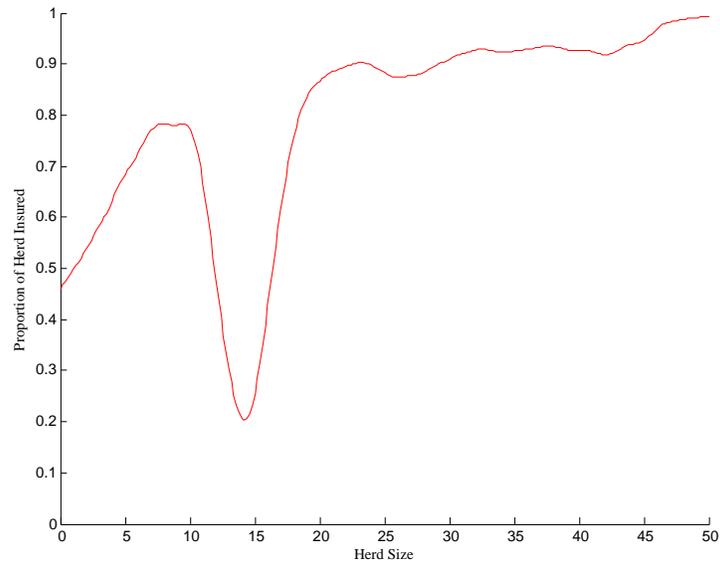
purchase decisions as a fraction of the herd into  $\{0.0, .02, .04, \dots .98, 1.0\}$  and resolve Equation 10 using the actuarially fair price of insurance.

Figure 9 plots the optimal partial insurance decision (smoothed) for households with heterogeneous herd sizes. The results closely match the shape of the willingness to pay (for full insurance) curve, with one important distinction. While households can choose zero insurance, it is optimal for all households, regardless of their proximity to the asset threshold, to insure at least some portion of the herd. In line with the intuition gleaned from the original dynamic option value presented in Figure 7, this optimal policy function suggests insurance can engender positive welfare benefits for all households. The policy function for Micawber households dictates a low level of insurance (only 20% of the herd), whereas households above the threshold insure closer to 90% with proportion insured increasing as asset levels move away from the threshold. Threshold households clearly benefit from some protection, but the real impact of insurance requires taking a deeper look at the budget constraint and optimal behavior.

Remember that a household must choose to allocate their cash on hand between consumption, insurance, and investment back into the herd. Threshold households have a high shadow price of liquidity. In the absence of insurance, these households could choose to forgo consumption in order to build up the herd. But in a risky environment, it may not seem worth it. Even if they are able to get above the threshold, a bad shock can send them right back to where they started. However, in the presence of insurance, the promise of a safety net which prevents against future collapse can actually incentivize investment. If herds can be protected once they reach the asset threshold, then it's more rewarding to attempt to rebuild the herd. If they are able to reach a new threshold herd level, it then becomes optimal to insure.

This is exactly what we see. Figures 10 and 11 show the optimal investment and consumption choices under autarky and in the presence of an insurance market. Threshold

Figure 9: Optimal Insurance Coverage



households insure only a small portion of their herd, but their optimal consumption and investment also change. They consume less and invest more. These households benefit dynamically from the very presence of an insurance market, even if they barely insure today. The possibility of insuring more once their herd gets big enough may be enough incentive to take on the extra risk of increased investment. These households may choose to suffer through some tough low-consumption years as a result, but in the long run they can be made better off.

An opposite behavioral effect results for households above the asset threshold. In the absence of a functioning formal insurance market, these households informally “insure” by investing more in their herds, while forgoing consumption. When formal insurance becomes available, households instead choose to use their cash on hand to purchase insurance and consume more in good years, forgoing additional investment. Such households continue to invest, but they invest less than if they were uninsured. This finding supplements findings by Francesca de Nicola (2011) who also predicts a reduction of investment when insurance is introduced.

This behavioral effect is especially pronounced once households reach the high level equilibrium. At that point, the marginal benefit of investing is low, so households prefer to allocate their resources toward consumption. In addition, these households display a remarkably higher willingness to pay for insurance in order to maintain their high level of welfare.

These results suggest the importance of considering the asset poverty trap in analyzing demand for insurance. If such an asset threshold actually exists, and households are able to perceive the threshold and its implications, then such a threshold will have huge implications for the optimal insurance purchase decision.

Figure 10: Optimal Investment Decisions for various herd sizes

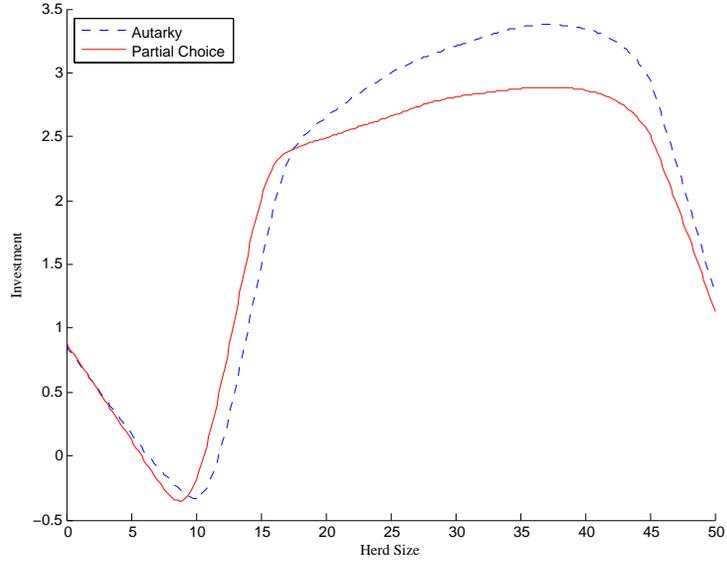
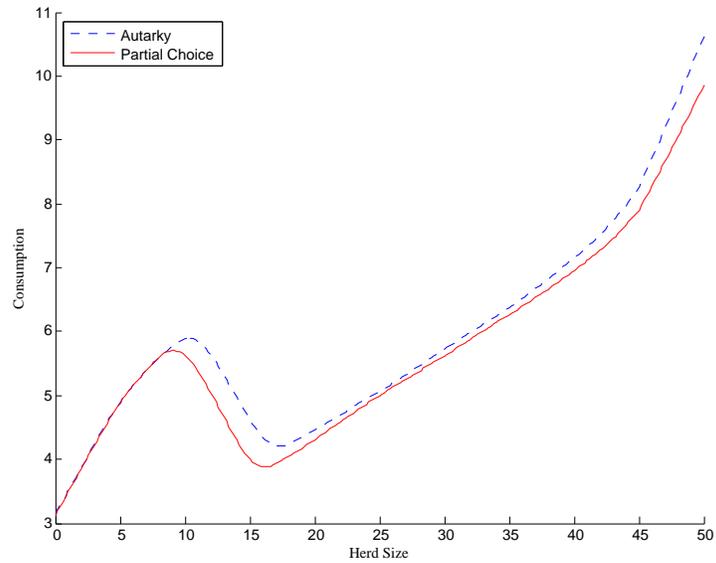


Figure 11: Optimal Consumption Decisions for various herd sizes



## 6 Poverty Dynamics in Marsabit

While modeling the insurance decision in the context of livestock insurance for pastoralists, thus far we have not explicitly considered what the benefits will mean for poverty dynamics of a specific population. Rather, up to this point our results apply more generally to asset insurance in the context of poverty traps. In general, the model develops intuition toward understanding how asset insurance will influence behavior when dynamic asset thresholds may induce poverty traps, and how such asset thresholds affect demand for asset insurance. This is useful in a broad context.

However, there may also be some benefit to an attempt toward defining the implications of this model in a specific context, especially with regard to poverty dynamics. We make that attempt here, with a few disclaimers. Specifying the precise structure of the poverty trap mechanism is beyond the scope of this paper, and we are forced instead to use the basic assumptions of production technologies. We also make some large assumptions about the structure of shocks, an area which we may be able to improve upon in the future. Despite some obvious lofty assumptions, we use empirical data of the distribution of herd sizes in Marsabit district of northern Kenya. The data includes a random sample of households in Marsabit district in 2011.

Using the empirical livestock distribution across households, we then simulate the optimal consumption and investment decisions for households who are subjected to a series of shocks. We do the same for households who are faced with a decision of insuring any fraction of their livestock herd. Doing so allows us to also consider the evolution of various indicators of economic performance with and without insurance. For this analysis we focus on 3 common indicators: the poverty gap, poverty headcount and GDP.

The estimate of GDP is fairly straightforward. It is simply the sum of individual production. In our case we use:

$$GDP_t = \sum_{i=1 \dots n} f(H_{i,t}) \quad (17)$$

where  $n$  is the total number of individuals in the sample population.

The other two measures, poverty gap and headcount, are in the family of Foster-Greer-Thorbecke (FGT) measures, and are calculated as follows:

$$P_\gamma^y = \frac{1}{n} \sum_{y_j < y_p} \left( \frac{y_p - y_j}{y_p} \right)^\gamma \quad (18)$$

Here, the income poverty line  $y_p$  is the income generated by the asset level at which the kink in the implied production technology occurs. Individual  $j$ 's income  $y_j$  is estimated using  $f(H_i)$ , and  $\gamma$  is the FGT sensitivity parameter. For the poverty headcount,  $\gamma$  is equal to zero, and for the poverty gap  $\gamma$  equals 1.

The predicted evolution of these three economic indicators in Marsabit with and without IBLI are presented in Figure 12. Looking first at the poverty gap, we see that the gap reduces with livestock insurance. This is a result of the shifting equilibrium effect. Because the low level equilibrium shifts upward, households are closer to the poverty threshold. In fact, the estimated gap is biased upward if we consider also the shifting threshold effect

which reduces the asset level, and thereby the income level necessary to escape the poverty trap. Our calculation instead holds the threshold income level  $y_p$  constant. If we allowed  $y_p$  to shift once insurance was made available then we would expect that the gap would be even smaller.

The poverty headcount decreases and then flattens out with IBLI, whereas it steadily increases under the autarkic setting. Because households just below the asset threshold are able to move out of the poverty trap once IBLI is available, we observe a reduction in the number of households below the poverty income threshold  $y_p$ . Furthermore, once out of the trap, these households are no longer vulnerable to collapse because they can insure. On the contrary, uninsured households remain vulnerable to collapse. This susceptibility to collapse, combined with an inability to escape once collapsed, is why we see a higher poverty headcount in the absence of IBLI.

Finally, we consider the sum of household production, to obtain an estimate of economy GDP which we measure in TLU rather than monetary value. Here again we see benefits due to IBLI. These results suggest GDP approximately 3% higher after 10 years, and approximately 5% higher after 25 years.

## 7 Concluding Remarks

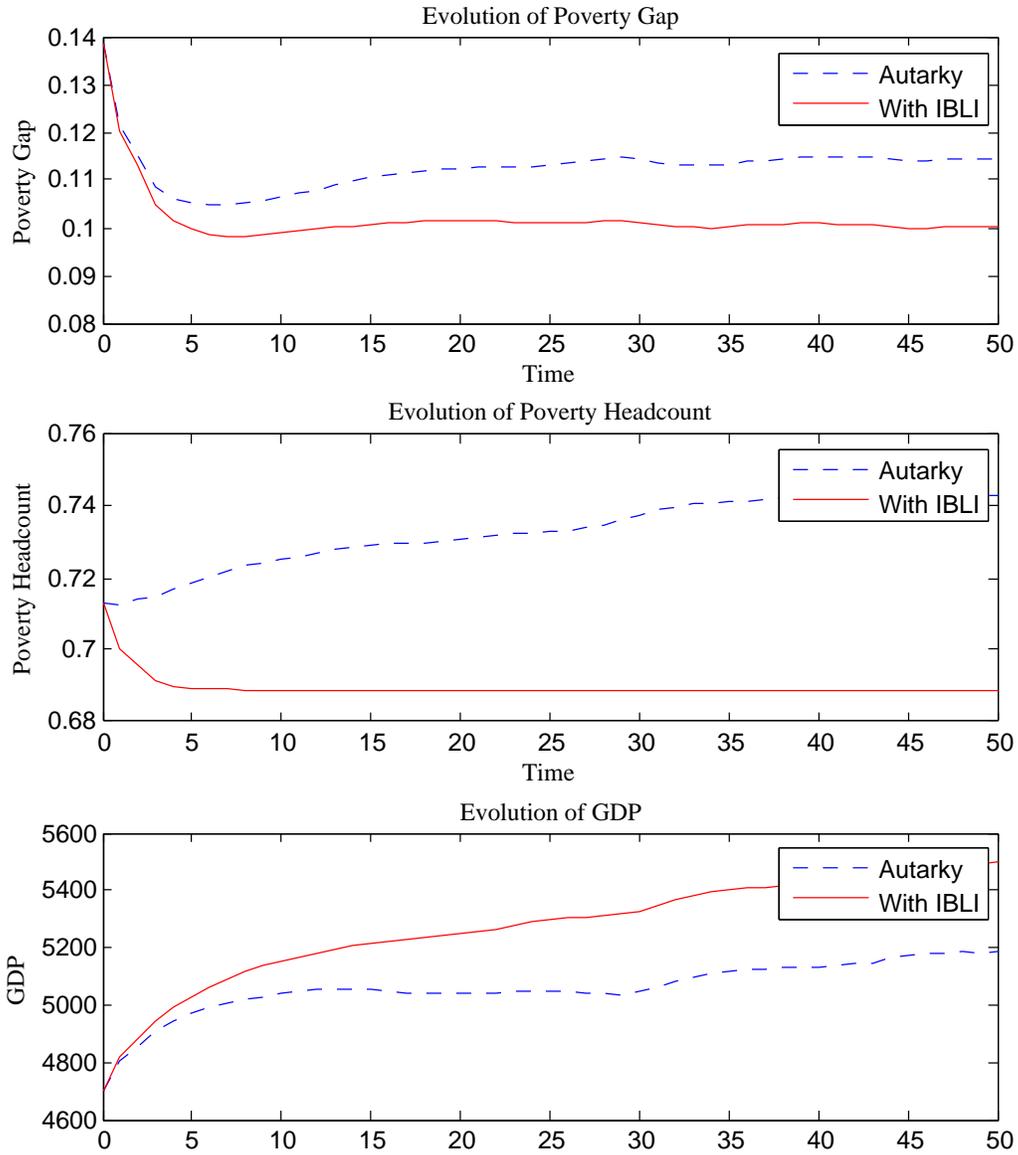
Households in developing countries often suffer from a missing insurance market. In January 2010 index-based livestock insurance (IBLI) was introduced to pastoralists in northern Kenya in order to fill this gap. In this paper we use dynamic programming techniques to generate an option value measure of the value of IBLI for individuals with various levels of herd size. This allows for an assessment of welfare gains from the institutional innovation, as well as a theoretical framework for an empirical demand analysis.

In particular, the model developed in this paper provides a theoretical framework for analyzing how IBLI will influence dynamically optimal behavior at or around a poverty threshold. We find that when households pre-commit to actuarially fair insurance for a lifetime, far fewer herds are vulnerable to collapsing to a low level equilibrium, and some herds otherwise trapped at a low level equilibrium suddenly have a chance to “get over the hump”. We also show that the average equilibrium levels are substantially higher with insurance. Together these findings imply that the option value of insurance depends not only on the benefits of income or asset smoothing, but also on a reduction in vulnerability, and the ability of the agent to potentially achieve higher future welfare.

By looking at optimal consumption, investment and insurance purchase decisions we find that households near a critical asset threshold will be unwilling to purchase full insurance at the actuarially fair price. However, when given the option to partially insure, these households will insure in small amounts. Such households find it optimal to forgo consumption and increase investment in an attempt to reach the critical asset threshold. This means insurance causes an increase in the marginal benefit of investing. If they have good fortune and reach the threshold, it then becomes optimal to insure a larger portion of the herd in an effort to prevent against future collapse. In this way, these initially “trapped” households can benefit greatly from insurance even if they choose not to insure at the outset.

Understanding how behavioral choice changes in the presence of IBLI is critical to under-

Figure 12: Evolution of Poverty Measures



standing the effect of IBLI and other similar products seeking to address long term poverty. Furthermore, addressing the impact in the context of poverty traps can provide insight that is otherwise overlooked. These considerations can dramatically change the results of any analysis assessing the effect of this type of product. When we apply the model's predictions to the empirical asset distribution in Marsabit, we find evidence of a reduction in the poverty headcount and gap, as well as increased GDP levels in the long run.

As index-based risk transfer products become popular in developing country settings, a solid theory of the dynamic effects, both in terms of optimal choices and welfare gains, is warranted. This paper seeks to address this important issue.

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## Appendix A: Tables

Table 1: Parameters used in Numerical Simulations

Production Technology Parameters
$\gamma_L=0.25$ $\gamma_H=0.56$ $\underline{f}=2.725$ $\alpha_L=1.6$ $\alpha_H=1.33$
Utility Function Parameters
$\beta = 0.95$ $\rho = 1.5$
Insurance Contract Parameters
$p=.0275$ $s=.15$
Random Shocks
$\theta=\{0.0, .05, .10, .15, .20, .25, .30, .35, .40, .45, .50, .55, .60\}$ $\epsilon=\{0.0, .005, .010, .015\}$ $P(\theta)=\{.3226 .3226 .1489 .0744 .0546 .0298 .0124 .0099 .0050 .0050 .0050 .0050 .0050\}$ $P(\epsilon)=\{.55, .15, .15, .15\}$