Dynamic Demand for Index-Based Asset Insurance in the Presence of Poverty Traps

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Abstract:

More than 3 million households in northern Kenya's arid and semi arid lands depend primarily on livestock as their main livelihood. The risk of drought renders these pastoralist households vulnerable to large herd mortality shocks, and thereby large income shocks as well. Index-based insurance products offer great promise for managing climate related risks that vulnerable households face. This project proposes a theoretical dynamic demand analysis of the index based livestock insurance (IBLI) pilot in Marsabit district of northern Kenya. We use dynamic programming techniques to generate an option value measure of welfare gains attributable to IBLI for individuals with various levels of herd size. In particular, we analyze how insurance influences dynamically optimal behavior near a poverty threshold. Similar to other studies, we find that households with asset levels below a critical asset threshold may not choose to purchase insurance. However, unlike previous studies, we show that the very presence of a formal insurance market actually encourages greater investment by "trapped" households, which may result in decreased poverty levels over time.

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 large herd mortality shocks, resulting in large 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.

Vulnerable households should have a higher option value for insurance if IBLI 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. 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, if a high option value exists for households at or near a poverty threshold, then we expect to see evidence of higher demand for IBLI by individuals around a critical asset threshold. 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. We also review the small literature regarding demand for index insurance products in developing countries. In general, demand has been much lower than anticipated. When demand is especially low, identifying the factors suppressing demand becomes complicated, which may help to explain a gap in the literature related to empirical demand analyses of index insurance products. Since demand for IBLI in its first year of the pilot was relatively high, this research hopes to address this gap by using the theoretical model presented in Section 3 to develop an empirical model for IBLI demand. This theoretical model of demand for index based livestock insurance carefully accounts for herd 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. In sections 4.1 and 4.2 we provide a discussion of the results of the numerical analysis including the optimal herd accumulation paths over time and a dynamic option value for IBLI in this scenario. Our results suggest that the welfare gains from IBLI for a given household stem from three 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 average high level equilibrium is substantially higher with insurance. Third, 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. Section 6 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, risk can affect the poor in two distinct ways: *ex ante* and *ex post*. First, the *ex ante* effect of risk stems from allocating resources to activities with lower risk but lower return in order to minimize risk. Second, *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/or other undesireable effects (Alderman and Haque 2007, Skees and Collier 2008). In a world where risk abounds, 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 mechansim 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 determinance 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), (Chantarat et al. 2007, Chantarat 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, if the reduction in risk brought about by insurance stimulates investment in higher return (albeit higher risk) activities, then 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. Of course the benefits of insurance cannot be realized in the absence of demand for the product, which is where we turn next.

2.3 Demand for Index-based Insurance

Griliches seminal 1957 paper on the economics of agricultural technology adoption suggests an s-shaped model of technological adoption where adoption begins with only a handful of people. This slowly spreads throughout a population as additional people begin to accept the new technology. This is followed by a period of rapid adoption where the remaining population of un-adopters also choose to adopt the new agricultural technology. Early adopters are in essence risk takers, experimenting with a new technology before its true value has been demonstrated.

Index insurance adoption in developing countries seems to be exhibiting a similar pattern. Early participation with index insurance products has generally been low. When demand is especially low, identifying the factors suppressing demand becomes complicated, which may help to explain a gap in the literature related to empirical demand analyses of index insurance products. Giné et al. (2010) provides a nice synthesis of the literature on the topic supplemented by empirical findings from a case study of rainfall index insurance in India (Giné et al. 2008, Cole et al. 2010), offering a list of seven primary factors thought to limit demand.

1. **Price**- For obvious reasons we expect a higher price to be associated with lower demand. For the India case study, Cole et al. (2010) find a price elasticity of .66 - .88, demonstrating that price is indeed a significant factor influencing demand.

2. **Availability of alternative risk-sharing arrangements**- If households have access to alternative informal insurance arrangements then the value of formal insurance decreases and we expect lower demand. Sakurai and Reardon (1997) present a model of

potential demand for drought insurance in Burkina Faso and suggest that the availability of food aid creates a moral hazard problem, decreasing demand for insurance. However, empirical evidence of this factor affecting realized demand is lacking.

3. **Risk aversion and basis risk-** It is generally held that farmers' aversion to risk affects the composition of their asset portfolio (see Rosenzweig and Binswanger 1993). It is therefore natural that we would expect demand to be increasing in risk aversion. Similarly, we expect demand to be declining in basis risk. That is, we expect demand to increase as the correlation between realized losses and insurance payoffs increases. As a further extension, it is possible for farmer perceptions about the insured risk to differ from the information used to price the contract, in which case expected basis risk differs from the true basis risk. Mullally (2011) shows that such dissonance can negatively affect demand.

4. **Liquidity constraints-** Seasonality is an important issue in agricultural settings, and often induces a binding liquidity constraint at certain critical times of the year. Thus, even households with a high willingness-to-pay for insurance may lack the liquid assets necessary to purchase insurance during sale periods. Giné et al. (2008) and Cole et al. (2010) both find that insurance demand is postively correlated with wealth. In addition, randomly relaxing the liquidity constraint by offering various payment levels to respondents for time spent with an insurance educator significantly increases demand.

5. **Understanding and learning-** Foster and Rosenzweig (1995) suggest that imperfect knowledge about a new product can be a significant barrier to adopting a new technology. This is certainly likely to apply to index insurance, a complicated financial product with little precedence in remote regions of developing countries where many people lack formal education. While Giné et al. find no evidence that financial education increases takeup, Foster and Rosenzweig suggest that people are likely to learn from others' experiences with new technologies, implying that the learning process may occur over long periods of time.

6. **Trust-** In order for insurance to be of any value, the insured must have trust in the insurance provider that a payment will be reliably made when it is supposed to. The India case study finds that endorsement of the insurance product by a trusted local individual significantly increases demand. Cai et al. (2010) similarly find evidence that trust in the institution associated with a microinsurance program in southwestern China is an important determinant of demand.

7. **Framing and behavioral influences-** Recent advances in behavioral economics suggests that subtle changes in the way a contract is presented could significantly influence demand. The India case study tests for a number of behavioral biases and framing effects, but does not find evidence of any influence on takeup rates.

These factors together have been hypothesized to influence demand, but empirical evidence is limited at best. In this paper, we seek to build a theoretical foundation for empirically analyzing demand for IBLI. We would expect realized demand to match the results of our simulations if our model is correct and outside barriers such as those discussed here do not exist.

3 A Dynamic Model of IBLI

In this section we briefly outline a household model of index based livestock insurance in the presence of risk and poverty traps. A more complete description of the model is presented in Appendix B.

Each household has an initial endowment in the form of a livestock herd (H_0). Herd loss is dictated by a mortality function which depends on a random aggregate shock (θ_t), an idiosyncratic shock (ϵ_t) specific to the herd, and herd size in a given period (H_t). Each herd produces a flow of benefits $f(H_t)$. 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.

If the household chooses to purchase insurance for the next season, it must pay a premium equal to the price of insurance (p) times the number of TLU insured (I_t). The household doesn't know in advance if the insurance index i will cause the insurance to pay out in the following period. This risk enters through θ_t. If the index is such that a payout is made, then the household also receives the indemnity payment (δ_t) times the number of TLU insured. Timing is critical here. The household's decision today is whether or not to insure the herd for the following season, and similarly, the payout is based on the previous period's insurance purchase decision. We can now define the equation of motion for the herd:

$$H_{t+1} = H_t + f(H_t) - m(\theta_t, \epsilon_t, H_t) - c_t - pI_t + \delta_t(i_t(\theta_t))I_{t-1} \tag{1}$$

We allow households to choose between two different production technologies: a low return and a high return technology. With the low return technology (sedentarism), we assume that households are able to supplement their incomes with petty trade in the village (for example by selling milk or handicrafts.) This supplemental fixed income is denoted as $\underline{f}$. Equation 2 below thus defines the structural form assumed for the production technologies:

$$f(H_t) = \begin{cases} \alpha H_t^{\gamma_L} + \underline{f} & \text{if } H_t \leq \hat{H} \\ \alpha H_t^{\gamma_H} & \text{if } H_t > \hat{H} \end{cases} \tag{2}$$

where $0 < \gamma_L < \gamma_H < 1$. The optimally chosen production technology creates nonconvexities in the implicit production function (defined by the outer envelope of the two production technologies). These nonconvexities coupled with borrowing constraints drive the poverty trap mechanisms. Figure 1 shows the general shape of $f(H_t)$ under the assumptions set forth.

We are now ready to specify the household's objective function. The household is assumed to be risk averse and will maximize the expected intertemporal utility V by choosing consumption and insurance for each time period, with expected utility at time t denoted as u_t which is a function of consumption c at time t. Implicitly, the household is also deciding how much to invest back in the herd for future benefits. The maximization problem is characterized by the following:

$$V(H_t, I_{t-1}) = \max_{c_t > 0,\, I_t = \{0, H_t\}} \quad u_t(c_t) + \beta E[V(H_{t+1}, I_t)] \tag{3}$$

subject to the equation of motion for herd dynamics (Equation 1) where β is the time discount rate.

The solution to this problem finds the optimal consumption, insurance and investment decisions in each year. We conduct the analysis by comparing two cases. First, we consider optimal consumption and investment decisions when insurance is permanently mandated. Comparing this situation to an autarkic environment where no formal insurance market exists provides useful insights into the value of insurance. 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 simple 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. 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 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 $z(H_t, I_{t-1})$ is then defined as the certain consumption transfer which would just make the constrained (no insurance) value function equal to the unconstrained (with insurance) value function. Formally:

$$V^*_I(H_t, I_{t-1}) = V^*_{NI}(H_t + z(H_t, I_{t-1}), I_{t-1}) \tag{4}$$

Solving for z 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:

$$V^*_I(H_t - z(H_t, I_{t-1}), I_{t-1}) = V^*_{NI}(H_t, I_{t-1}) \tag{5}$$

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 Mandated Permanent Insurance

4.1 Optimal Herd Accumulation

Figure 2 demonstrates the mean herd accumulation paths over a large number of simulations for various levels of initial herd size under autarky and with mandated permanent insurance.[1] Several things are worth noting. First, based on the assumptions set forth by the model, the highest mean herd size achieved under autarky at the end of 50 years is 14.7 TLU. Initial endowment clearly matters, 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, especially for those with initial herd size around 8 and above. This shows a high level of vulnerability for households with an initial herd size between 8 and 11 TLU (vulnerability here refers to a high probability of collapsing to a low level equilibrium). Moreover, households with an initial endowment below 8 TLU appear destined, at least on average, for a low level equilibrium of 4.4 TLU.

When full insurance is provided, the average path for those with 7.6 TLU or less is still movement toward a low level equilibrium, though the ending herd size of 4.9 TLU after 50 years is slightly higher than the autarky low-level equilibrium. Note that the mean initial herd threshold level for divergence toward the low level equilibrium has shifted downward, implying that more households are able to achieve positive herd growth. Moreover, the mean path under insurance is much smoother. All households with an initial herd size greater than 8.2 TLU on average head toward a high level equilibrium. In addition, the high level equilibrium is notably higher than the autarky level: with an average herd size of 20.6 TLU after 50 years. This higher level is reached because the effect of negative shocks is reduced.

In contrast to the *average* herd accumulation paths observed in Figure 2, Figure 3 plots the *median* herd accumulation paths over a large number of simulations for heterogeneous levels of herd size with and without insurance. These paths also 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.

Table 2 describes the typical ending herd sizes for the 25th, 50th and 75th percentiles for various categories of households under autarky and with insurance. In the autarky case, households with an initial TLU endowment smaller than 8 TLU are, in essence, "trapped" in poverty. These households will move to the low level equilibrium with almost 100% probability. In contrast, in the presence of mandated insurance, households with 7.5 TLU or less appear "trapped." This seems to imply that insurance would be highly valuable to individuals with 7.6-8.0 TLU because they are trapped without insurance, but reach the high level equilibrium with greater than 50% probability when they insure their herd.

As we would expect, a much larger proportion of the population can be identified as vulnerable (likely to fall to a low equilibrium) when an insurance market is missing. This is clearly depicted in figure 4 which shows the probability of reaching a low level equilibrium with and without IBLI. Clearly, the probability of collapse to the low level equilibrium is high

[1] We take mean and median herd size over simulations for each initial herd size and each t.

for herds that are already below the poverty threshold (in a sense they have already collapsed and cannot escape). The probability of collapse declines sharply to zero when insurance is present. Alternatively, the probability of collapse without IBLI declines gradually as initial endowment increases. Note that the probability of collapse remains positive even for large herd sizes in the absence of an insurance market. In addition, the critical herd size at which herds appear to collapse with probability near 100% actually decreases when insurance is present.

Another way of thinking about this is to consider figure 5 which plots the 10th, 25th, 50th, 75th and 90th percentiles of the terminal herd size across simulations under autarky and with IBLI. This figure captures the essence of the discussion up to this point by depicting three things that happen when actuarially fair insurance is present:

1. **Vulnerability Effect:** Insurance offers a reduction in the vulnerability of collapse to the low level equilibrium. Even households with a herd as large as 15 TLU have a greater than 10% chance of falling to the low level equilibrium after 50 years in the autarky setting (Figure 4 shows that the probability of collapse is actually closer to 20%) . This is in sharp contrast to the case of insured livestock, where even the 10th percentile achieves positive herd growth if they are above the critical herd size threshold.

2. **Shifting Equilibrium Effect:** An insured herd is likely to reach a higher terminal herd size regardless of initial endowment than its uninsured counterpart. Note that even the low level equilibrium is higher for insured households.

3. **Smoothing Effect:** The path to accumulation involves fewer ups and downs; it is smoother. This is the effect we generally think of when we consider the value of insurance.

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 smoothing effect, but also effects 1 and 2. This may result in a greater willingness to pay for vulnerable households. 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 insurance. The value function is higher regardless of the initial endowment in the unconstrained (with IBLI) setting. As discussed earlier, we can take this one step further by constructing a dynamic option value. Here we consider the amount that must be taken from the unconstrained (with insurance) household to make them equally as well off as the constrained household. Figure 6 plots the option value for various levels of initial herd endowment.

Using this measure of a dynamic option value we see that the value of insurance is lowest for households trapped in poverty, though notably the value increases as households move closer to the poverty trap threshold. The clear jump in the option value occurs around 8 TLU. At this point insured herds are dramatically less vulnerable to collapse. In addition, the option value increases as vulnerability decreases and starts to taper off as herds become less vulnerable.

Notice, however, that the option value remains high for larger herds. This can be attributed to the shifting equilibrium and smoothing effects. That is, the reduction in risk which causes the median high level equilibrium to be much higher with insurance, around 20.6 TLU, compared to the autarkic case where the median ending herd size is 14.7 TLU, and the path itself is smoother with insurance.

To make the option value more interpretable, we consider the amount of cash transfer necessary in every period in order to make an uninsured household as well off as an insured household. To calculate this numerically, we iterate over small increases in consumption levels to find the amount of additional cash, used for consumption, that will make the constrained value function equal to the unconstrained value function. The results are shown in figure 7. Interestingly, the amount of cash transfer necessary is relatively high and increasing until about 8 TLU (initial herd size) where the cost of the cash transfer necessary to lift an uninsured household to the welfare of an insured household suddenly falls dramatically. For example, the cash transfer necessary for a household with 10 TLU is less than 30% the amount necessary for a household owning 8 TLU. This seems to imply that the amount of cash transfer necessary is highest for households that are trapped. The value declines as households become less vulnerable, where vulnerability refers to the probability of collapsing to the low level equilibrium, and it is lowest for households who are unlikely to end up at a low level equilibrium. This seems to support our hypothesis that vulnerable households will have much to gain from IBLI. In addition, we can compare the cost of a cash transfer to the cost of offering a 20% subsidy for full insurance. This is also demonstrated in figure 7. These results show that subsidizing smaller herds is considerably more cost effective than a cash transfer for poor households, while offering equivalent welfare gains.

It is worth taking a moment to address the apparent differences between the option value and the cash transfer. Each of these is meant to show who benefits the most from insurance, but they seem to tell two very different stories. First, the option value interpretation presented here looks at taking away from an insured household, to bring them to the welfare level of an uninsured household. The cash transfer is calculated in the opposite manner, giving to an uninsured household to make them as well off as an insured household. We would not necessarily expect these two different methods of calculating welfare gains to produce the same results. Second, the option value is a one time transfer expressed in asset space. In contrast, the cash transfer takes into account the marginal benefit of cash in every period used for consumption to make an uninsured household as well off as an insured household.

Who values insurance the most highly? The results presented in this section are clearly mixed. In the next section we relax the assumption of permanent mandated insurance and allow individuals to choose whether or not they will purchase insurance. This allows us to create a formal measure of willingness to pay which can help to answer this important question.

5 The Case of an Annual Insurance Decision

It may not always be optimal to insure the herd. Even if choosing to insure isn't optimal, a household can still 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. We once again solve the household's optimal decision problem, this time allowing households to choose whether or not they would like to purchase an annual insurance contract to fully insure their herd.

In addition, we construct a formal measure of an individual's willingness to pay for insurance by iterating 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 the insurance decision I_t is binary, where 1 equals full insurance and 0 implies no insurance. 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 λ, we define the willingness to pay for an agent with a herd size of H_t as the amount, $(1 + \overline{\lambda})p$ which satisfies the following:

$$V(H_t, \lambda\,; I_t = 1) \geq V(H_t\,; I_t = 0) \qquad \text{for all } \lambda \leq \overline{\lambda} \tag{6}$$

$$V(H_t, \lambda\,; I_t = 1) < V(H_t\,; I_t = 0) \qquad \text{for all } \lambda > \overline{\lambda} \tag{7}$$

We compute $\overline{\lambda}$ as follows. First, we discretize λ into $\{-0.4, -0.3, \cdots, 0.6\}$. Second, for each value of λ, we compute the optimal consumption, investment and insurance purchase decisions for all possible sets of state variables. Third, for each value of H_t and I_{t-1}, we search the value of $\overline{\lambda}$ at which the agent switches the optimal insurance purchase decision and thus conditions (6) and (7) hold.

Figure 8 shows $\overline{\lambda}(H_t)$. We observe a willingness to pay that is greater than the actuarially fair price for households above the Micawber threshold, as well as for households far below. However, households just below the threshold choose to not insure at the actuarially fair price. At first glance this seems contradictory, since the option value suggests a positive benefit can be had by all. The answer can be found by 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. Households just above the threshold have a lot to gain from insurance if it prevents them from falling below the threshold and collapsing to the low level equilibrium. The incentives are different for households below the threshold. In the absence of insurance, these households can 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, there is a greater incentive for households to build up the herd if it can be protected once they reach a large enough herd size. If they are able to reach that threshold herd level, then it becomes optimal to insure.

This is exactly what we see. Figures 9 and 10 show the optimal investment and consumption choices under autarky and in the presence of an insurance market. Households just below the threshold may by unwilling to purchase actuarially fair insurance, but nonetheless, their optimal behavior changes. They consume less and invest more. Perhaps contrary to intuition, these individuals can actually benefit dynamically from the very presence of an insurance market, even if they don't insure today. The possibility of insuring if 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 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, forgoing additional investment. Such households continue to invest, but they invest less than if they were uninsured. This is especially true 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.

6 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 model for analyzing how IBLI will influence dynamically optimal behavior at or around a poverty threshold. We find that when actuarially fair insurance is mandated, far fewer herds are vulnerable to collapsing to a low level equilibrium. In addition, the average high level equilibrium is substantially higher with insurance. This means that the option value of insurance depends both on a reduction in vulnerability as well as 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 just below a critical asset threshold will be unwilling to purchase insurance at the actuarially fair price. Nonetheless, these households are still affected by the presence of an insurance market as is demonstrated by their optimal consumption and investment decisions. Such households find it optimal to forgo consumption and increase investment in an attempt to reach the critical asset threshold. If they have good fortune and reach the threshold, it then becomes optimal to insure 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 understanding 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. 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 and Figures

Table 1: Parameters used in Numerical Simulation

Production Technology Parameters
γ_l=0.35 γ_h=0.55 $\underline{f}$=1.5 α=1.24
Mortality Function Parameters
$\overline{m}$=0.3 $\underline{m}$=0.05
Utility Function Parameters
$\beta = 0.95$ $R = 1.5$
Insurance Contract Parameters
p=.0325 s=.15 V_L=15,000
Random Shock
θ={-20,-10,0} ϵ=0 $g(\theta)$={.1,.25,.65}

Table 2: Typical Ending Herd Sizes for the 25th, 50th and 75th percentiles of various categories of households with and without insurance

	Autarky			IBLI		
Initial Herd Size	25*	50**	75***	25*	50**	75***
1.0-7.5 TLU	4.1	4.4	4.7	4.8	4.9	4.9
7.5-7.9 TLU	4.1	4.4	4.7	4.9	17.3	10.3
8.0-8.2 TLU	4.2	4.7	12.6	4.9	19.6	20.9
8.3-9.1 TLU	4.4	4.7	14.7	18.7	20.3	21.6
9.2-11.0 TLU	4.7	14.1	16.9	18.8	20.3	21.6
11.1+ TLU	10.8	14.7	17.9	18.9	20.6	21.6

*25th percentile
** 50th percentile
*** 75th percentile

Figure 1: Livestock Production Technologies

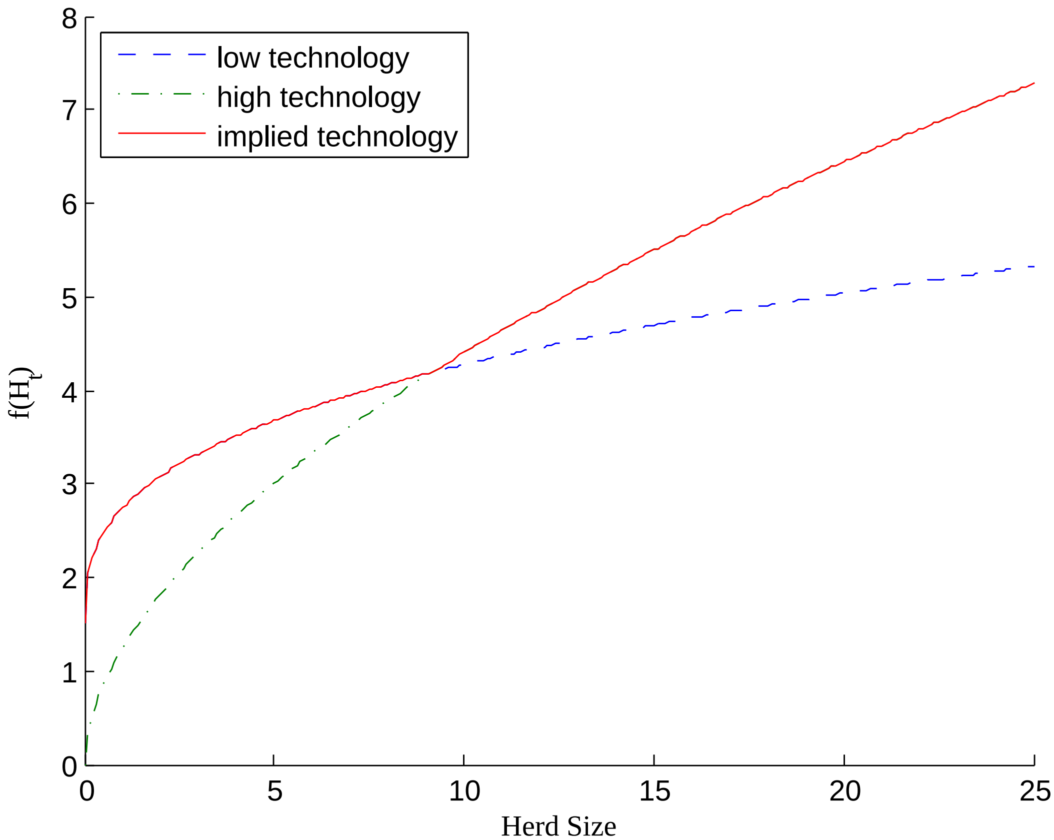


Figure 2: Mean herd accumulation paths for various initial herd sizes

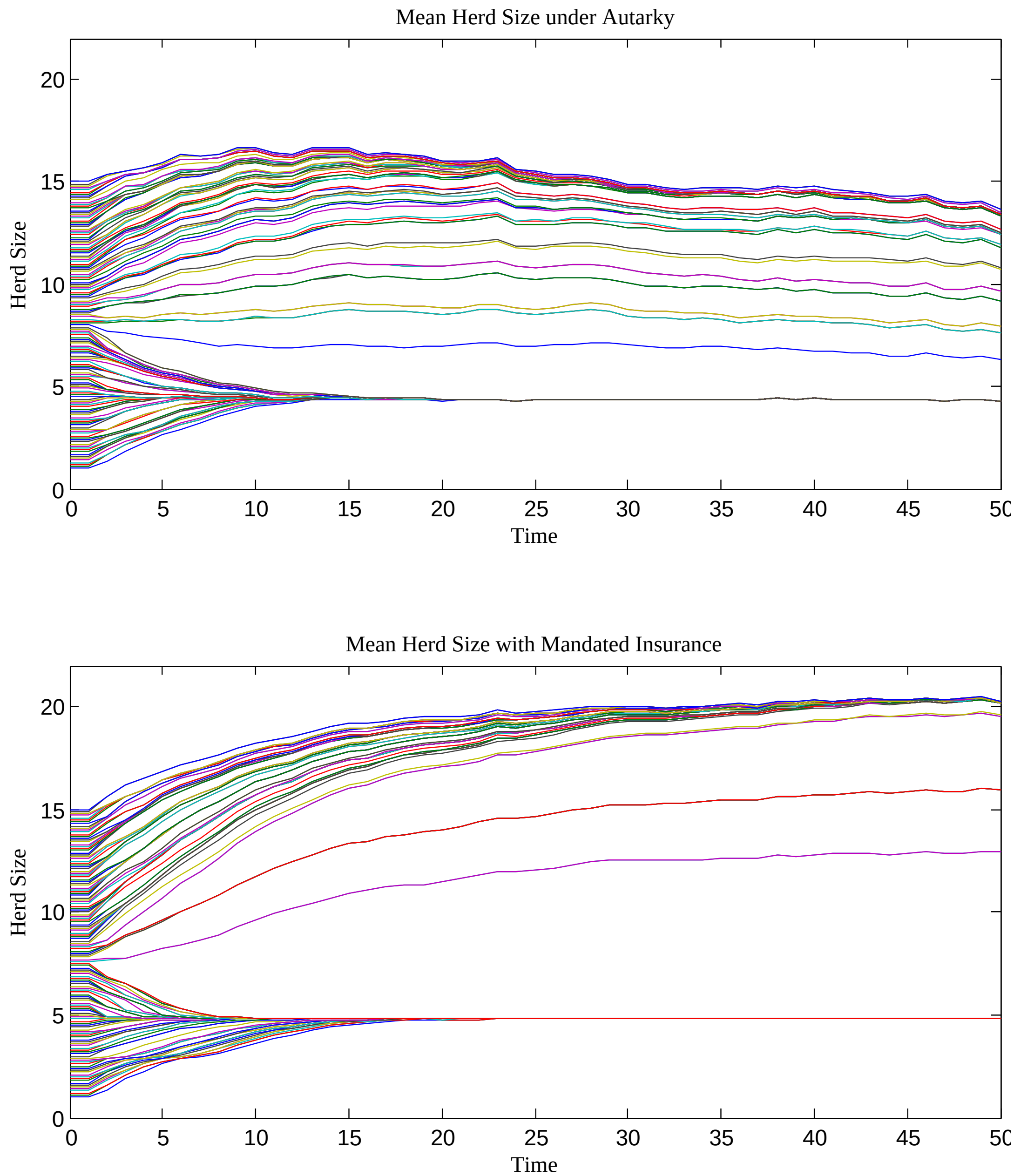


Figure 3: Median herd accumulation paths for various initial herd sizes

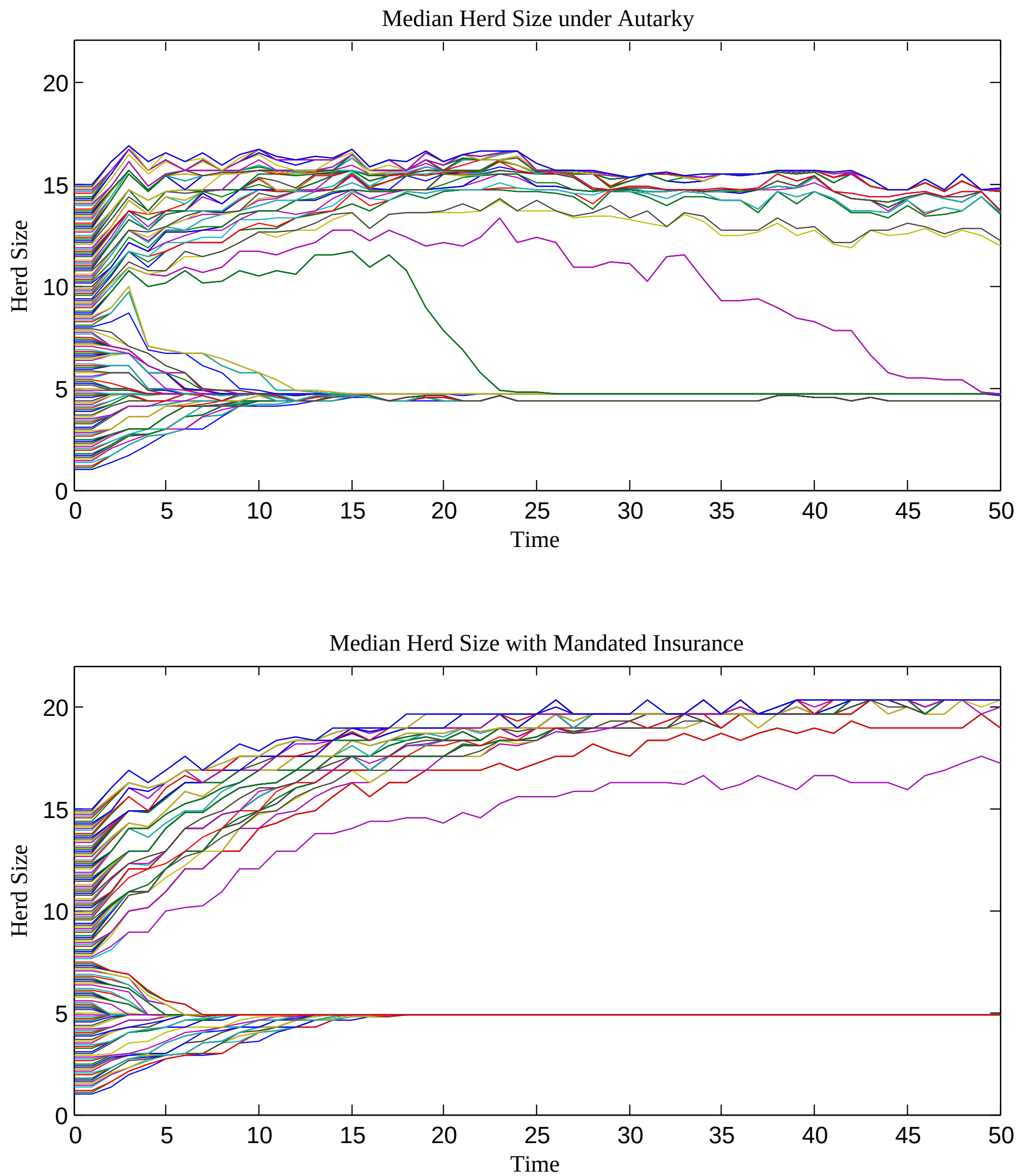


Figure 4: Probability of Collapse to a low level equilibrium with and without IBLI

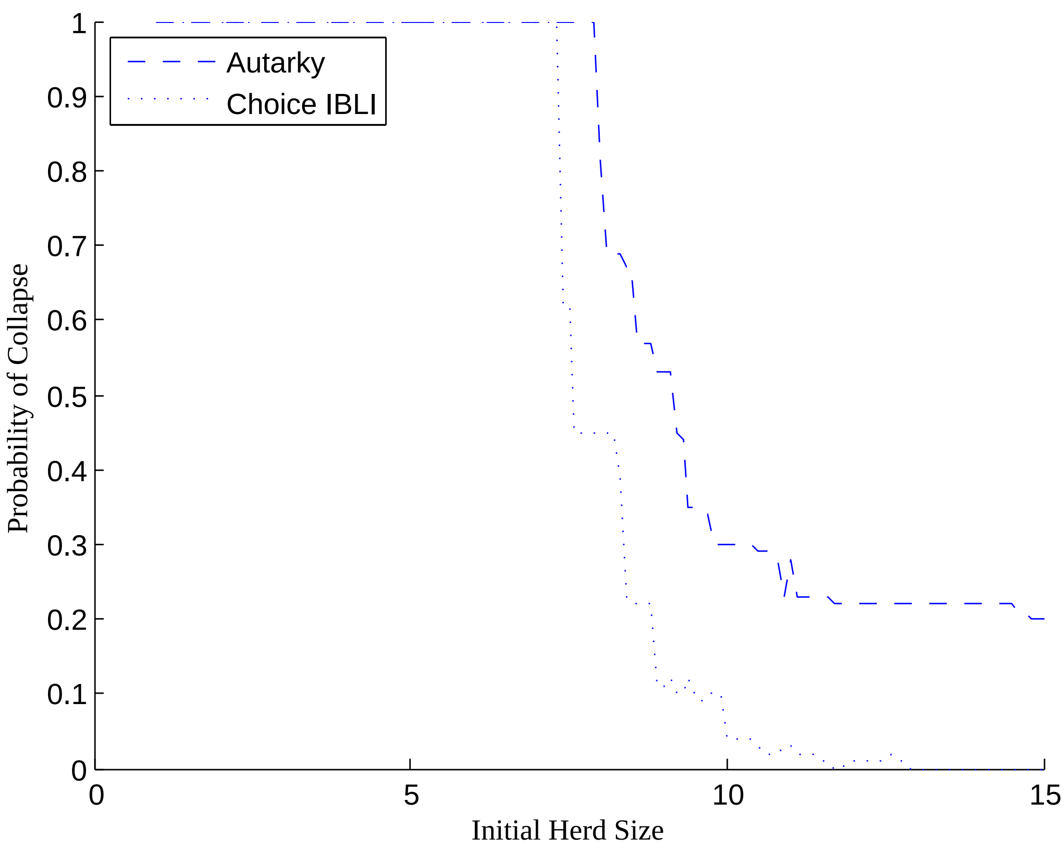
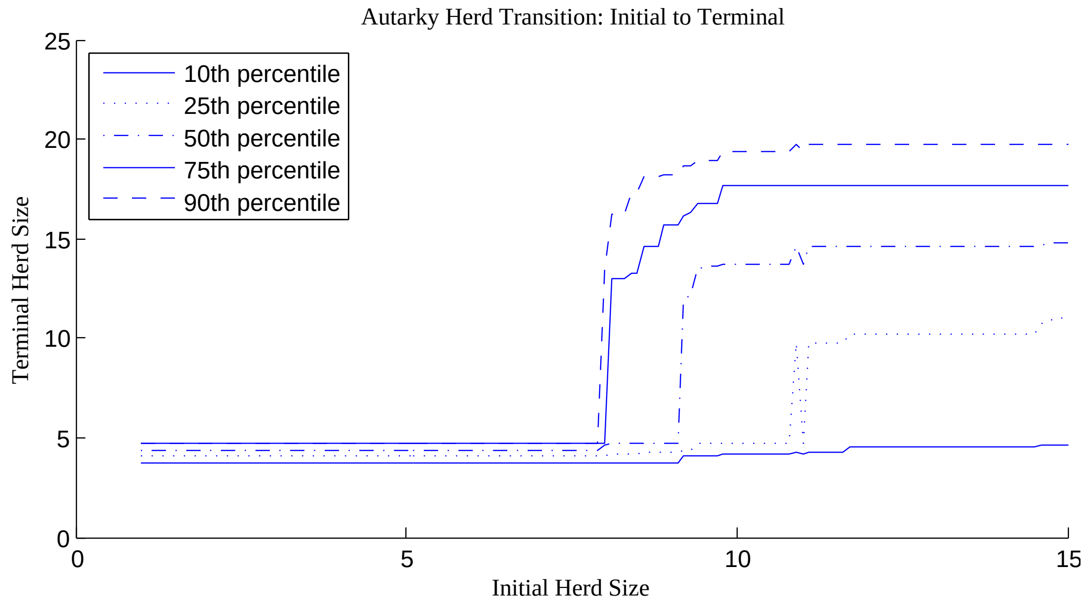


Figure 5: Herd Transition: Initial to Terminal



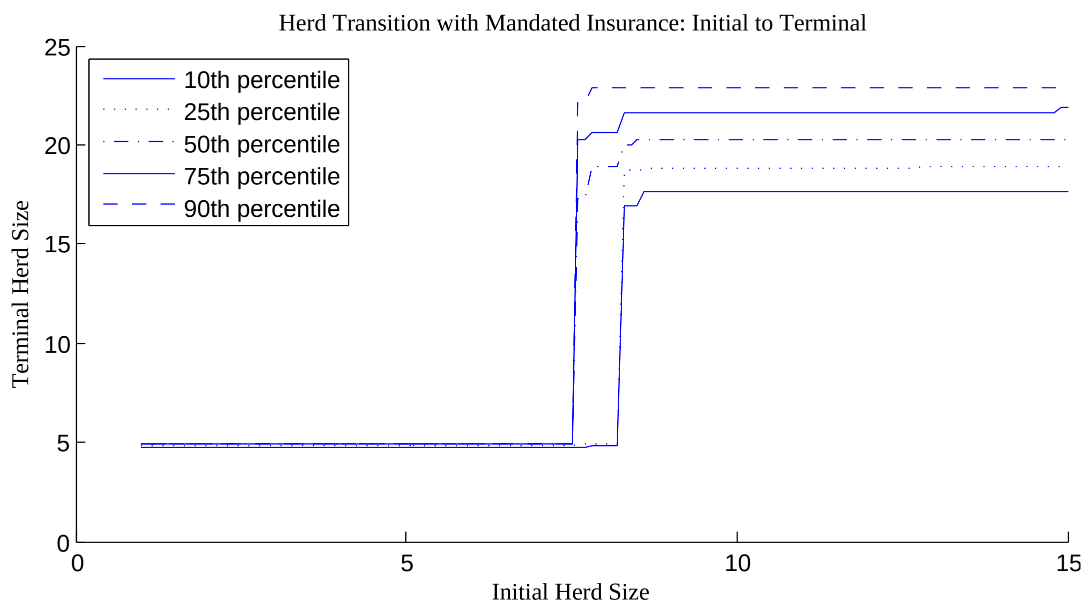


Figure 6: Dynamic Option Value

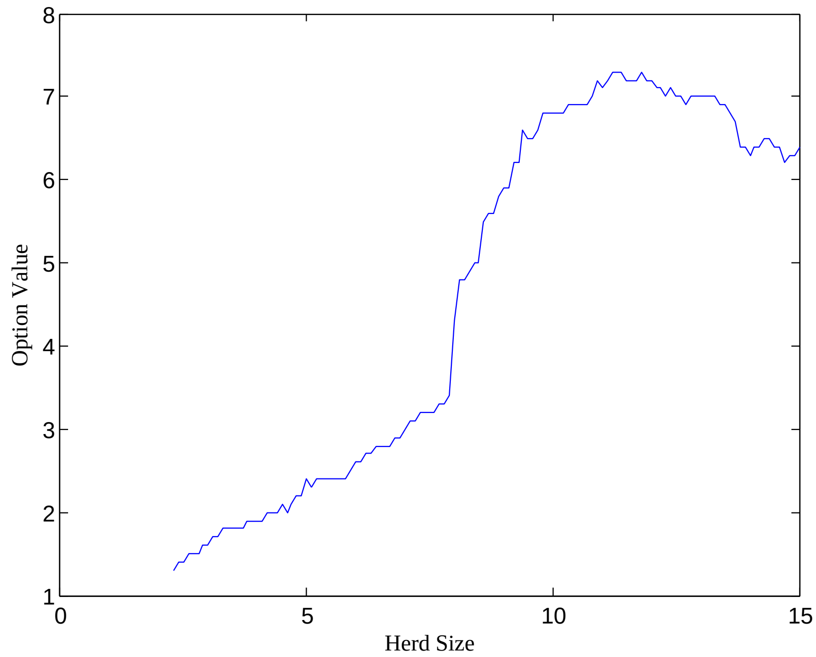


Figure 7: Amount of cash transfer necessary in every period to make an uninsured household as well off as an insured household, compared to cost of 20% subsidy on price of insurance

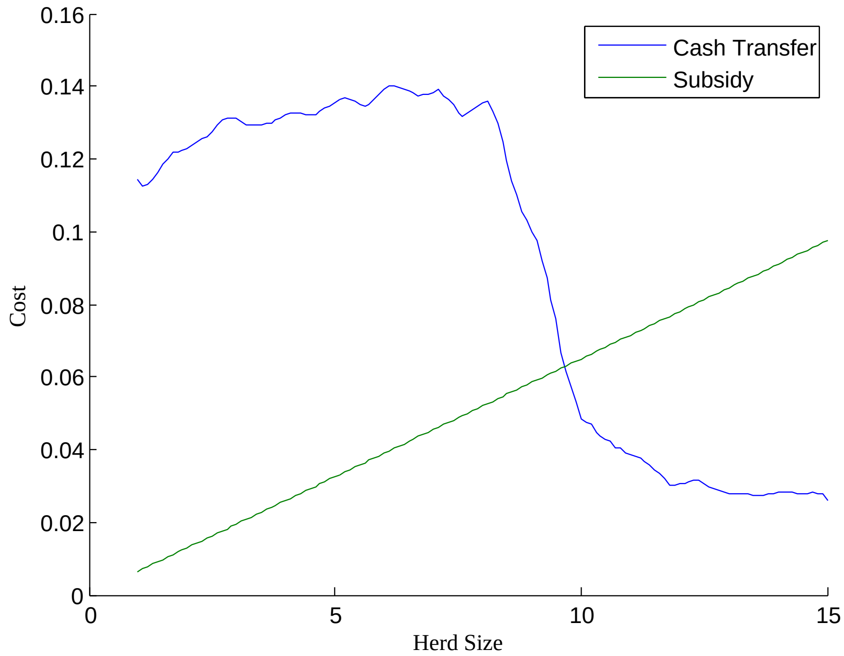


Figure 8: Willingness to Pay for IBLI

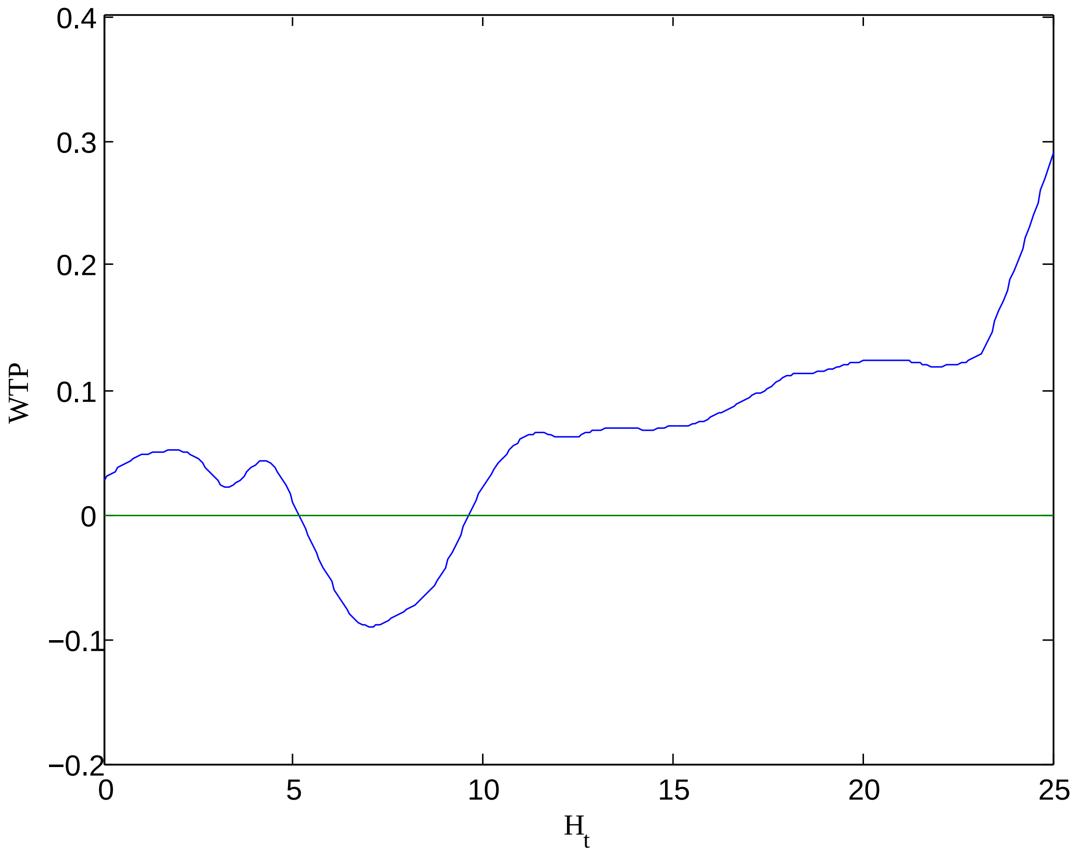


Figure 9: Optimal Investment Decisions for various herd sizes

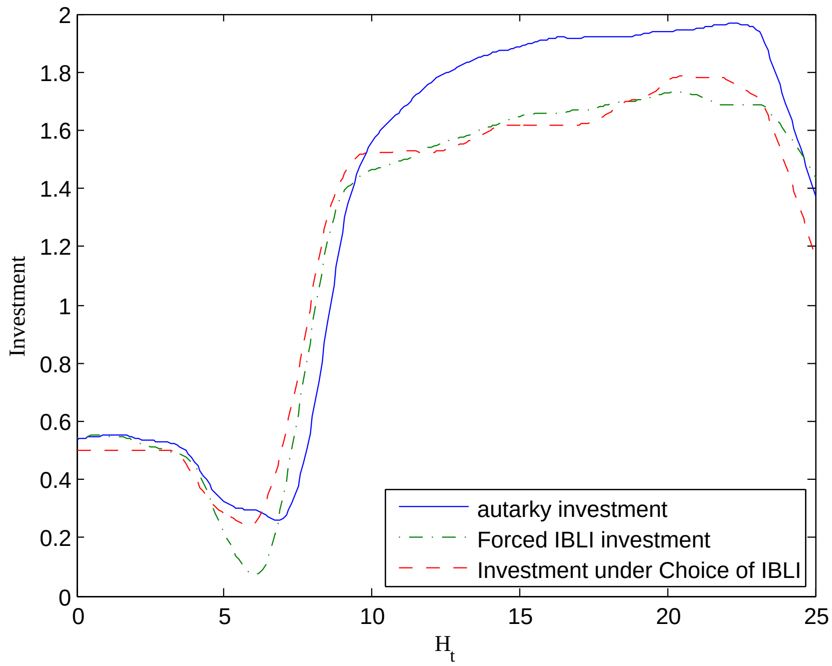
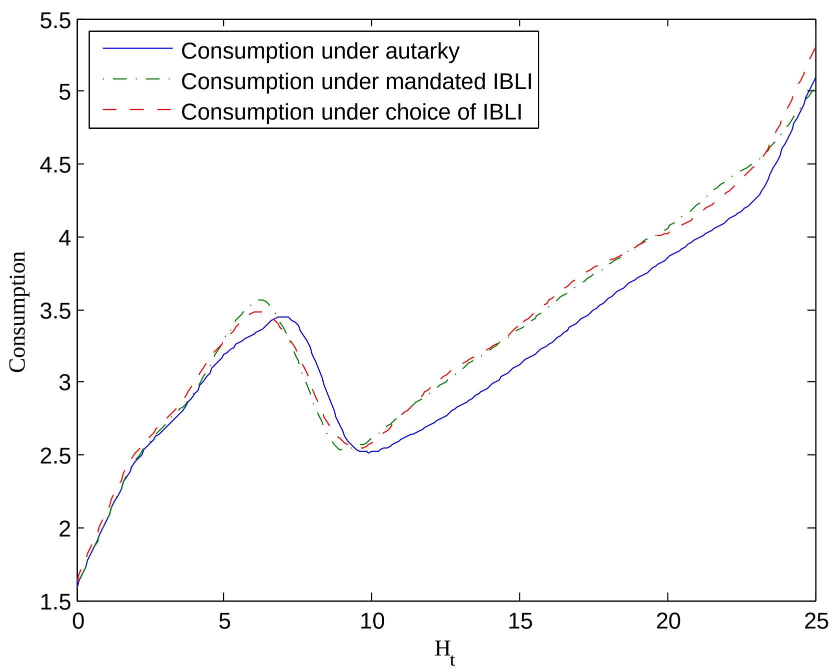


Figure 10: Optimal Consumption Decisions for various herd sizes



Appendix B: Full Model

In this section we present a household model of index based livestock insurance in the presence of risk and poverty traps. The model assumes that all output prices are given and constant. While the price of livestock is bound to change, and likely to be correlated with the weather, this simplification is necessary to build the basic intuition behind the model.[2]

Each household has an initial endowment in the form of a livestock herd (H_0). 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). Herd loss is dictated by a mortality function which depends on a random aggregate shock (θ_t), which is realized for all households at the end of the period, an idiosyncratic shock (ϵ_t) specific to the herd, and herd size in a given period (H_t). We assume the mortality function follows:

$$m(\theta_t, \epsilon_t, H_t) = \left(\frac{\min\{\theta_t, 0\}}{\underline{\theta}} \overline{m} - \epsilon_t + \underline{m} \right) H_t \tag{8}$$

where shocks are negative, $\underline{\theta}$ represents the worst possible shock or the minimum possible value of θ, $0 \leq \overline{m} \leq 1$ and $\underline{m}$ is average herd mortality in good conditions (i.e. in the absence of a negative covariate shock.) Note that the mortality function is assumed to be decreasing in θ_t and ϵ_t, so that limited rainfall or a negative idiosyncratic shock both result in higher mortality.

Herds also produce a flow of benefits $f(H_t)$. Following Dercon (1998) the flow function can be thought of as a livestock production function.[3] This flow (or production) function encompasses livestock births as well as "flows" such as milk products, which are the primary staple for people in this area.

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

$$H_{t+1} = H_t + f(H_t) - m(\theta_t, \epsilon_t, H_t) - c_t \tag{9}$$

The tradeoff is captured in this: a household can consume all the flows in a given period, but then the herd will be smaller in the next period if mortality is greater than zero. Similarly, the household can consume more than the flows. For example, the household could choose to slaughter part of the herd for consumption. 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.

Let us now consider insurance. If the household chooses to purchase insurance for the next season, it must pay a premium equal to the price of insurance (p) times the number of

[2]We acknowledge that price risk is an important factor in this setting. Future analysis will relax this assumption, and consider making price an equilibrium phenomenon.

[3]Perhaps more realistically, flows could also be a function of an idiosyncratic or covariate shock, but to keep things simple for now we leave it as deterministic.

TLU insured (I_t).[4] If the index is such that a payout is made, then the household also receives the indemnity payment (δ_t) times the number of TLU insured. Timing is critical here. The household's decision today is whether or not to insure the herd for the following season, and similarly, the payout is based on the previous period's insurance purchase decision. This can be incorporated directly into the equation of motion for the herd:

$$H_{t+1} = H_t + f(H_t) - m(\theta_t, \epsilon_t, H_t) - c_t - pI_t + \delta_t(i_t(\theta_t))I_{t-1} \tag{11}$$

The household doesn't know in advance if the insurance index i will cause the insurance to pay out in the following period. This risk enters through the random variable θ_t which is realized for all households at the end of time t. Hence, θ_t can be thought of as a negative covariate shock. More explicitly, if we think of θ_t as weather at time t, then we also assume that $\partial i/\partial\theta < 0$. That is, lower levels of rainfall (or more negative shocks) cause the index to increase. Hence, δ_t can be written as a function of the index i_t which depends on θ_t. The insurance contract specifies that an indemnity payout will be made if the index exceeds a certain strike point (s). In this way, the indemnity payment can be written as:

$$\delta_t = max\ ((i(\theta_t) - s)V_L,\ 0) \tag{12}$$

where V_L is the value of one TLU. Note that both V_L and s are known by the household in advance of the decision and assumed to be constant for this problem.

A noteable 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 δ_t. 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 distinct ways: the covariate shock θ_t, the idiosyncratic shock ϵ_t, and basis risk $(i(\theta_t) - m(\theta_t, \epsilon_t, H_t))$.

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 $\underline{H} < H_t \leq \overline{H}$), and then positive growth is observed for large levels of herd size (i.e. for $H_t > \overline{H}$) (see Lybbert et al. 2004 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

[4] 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 (I_t) must be less than or equal to the current period herd size (H_t):

$$I_t \leq H_t \tag{10}$$

Note that in practice this constraint is extremely difficult to enforce, and hence it will be ignored throughout this anlaysis. Furthermore, 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.

offers higher returns because livestock are brought to better pastures, whereas in sedentarism livestock are constrained to lower quality forage close to the village.[5]

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.) 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 13 below thus defines the structural form assumed for the production technologies:

$$f(H_t) = \begin{cases} \alpha H_t^{\gamma_L} + \underline{f} & \text{if } H_t \leq \hat{H} \\ \alpha H_t^{\gamma_H} & \text{if } H_t > \hat{H} \end{cases} \tag{13}$$

where $0 < \gamma_L < \gamma_H < 1$. 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 drive the poverty trap mechanisms. Figure 1 shows the general shape of $f(H_t)$ under the assumptions set forth.

We are now ready to specify the household's objective function. The household is assumed to be risk averse and will maximize the expected intertemporal utility V by choosing consumption and insurance for each time period, with expected utility at time t denoted as u_t which is a function of consumption c at time t. Implicitly, the household is also deciding how much to invest back in the herd for future benefits. For completeness, we specify the following utility function which assumes constant relative risk aversion:

$$u_t(c_t) = \frac{c_t^{1-R} - 1}{1 - R} \tag{14}$$

where R is the coefficient of relative risk aversion.

The maximization problem is characterized by the following:

$$V(H_t, I_{t-1}) = \max_{c_t > 0,\ I_t = \{0, H_t\}} \quad u_t(c_t) + \beta E[V(H_{t+1}, I_t)] \tag{15}$$

subject to the equation of motion for herd dynamics (Equation 11) where β is the time discount rate,

$$E[V(H_{t+1}, I_t)] = \int V(H_{t+1}, I_t)\ g(\theta_{t+1}, \epsilon_{t+1})\ d\theta\ d\epsilon \tag{16}$$

and $g(\theta_t, \epsilon_t)$ is the joint probability distribution of the covariate and idiosyncratic shock. Note that we are assuming that the agent can choose only either zero insurance $I_t = 0$ or full insurance, $I_t = H_t$.

[5] 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.

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 assume a heterogenous population with identical preferences and uniformly distributed initial asset levels.[6] Parameters such as the prices and insurance contract details (like the strike point and the value of a TLU) can be specified using observed values in Marsabit.[7] The production function will be specified to follow the dynamics outlined in the model.

There are multiple ways to model the distribution of the covariate weather shock. Initially, we make a grossly simplified distributional assumption.[8] To gain intuition, we first assume the distribution of the index perfectly follows weather, so the model assumes perfect insurance. That is: $i_t(\theta_t) = m(\theta_t, \epsilon_t, H_t)$ and there is no basis or idiosyncratic risk. Table 1 shows the parameters used in the numerical simulation.

The solution to the problem can be found by solving a stochastic dynamic programming problem. If the true value of all future consumption were known, then solving the agent's infinite horizon problem would be straightforward. Instead we use contraction mapping, by which it follows that the Bellman equation has a unique fixed point. We conduct the analysis by comparing two 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 when insurance is permanently mandated (i.e. where a government mandates full insurance in perpetuity). 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 mandatory 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.

Let it be clear that this numerical simulation is intended as a theoretical contribution demonstrating the benefits of index insurance to a specific population. While the simulation results should be relevant to northern Kenya, no claim is made for the empirical predictions of actual behavior in northern Kenya. Nonetheless, the results of these simulations can be used as a framework to empirically analyze demand, which we discuss in Section **??**.

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

[6]In order to realistically reflect the risky environment that pastoralists find themselves in, the parameters used for the numerical analysis should be calibrated to data collected in the local setting. This will be necessary if we are interested in the general equilibrium effects of insurance. This can be done using a panel dataset of household surveys conducted in Marsabit in 2009 and 2010. The data includes household level data on household and herd characteristics of 924 households. We leave this step for future work, and instead use knowledge of the local situation to quasi-calibrate as best we can.

[7]The insurance contract actually depends on the geographical coordinates of the household. As such, the index, indemnity payment and the price of insurance in the previous model should include regional subscripts which were suppressed for simplicity.

[8]Later analysis will consider calibrating these assumptions to historical data of weather patterns in the area. A similar distributional assumption will need to be made on an idiosyncratic error term once it is included.

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 $z(H_t, I_{t-1})$ is then defined as the certain consumption transfer which would just make the constrained (no insurance) value function equal to the unconstrained (with insurance) value function. Formally:

$$V_I^*(H_t, I_{t-1}) = V_{NI}^*(H_t + z(H_t, I_{t-1}), I_{t-1}) \tag{17}$$

Solving for z 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:

$$V_I^*(H_t - z(H_t, I_{t-1}), I_{t-1}) = V_{NI}^*(H_t, I_{t-1}) \tag{18}$$

Note that equation 17 is essentially a compensating variation measure of welfare gains whereas equation 18 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.

In practice, the derived dynamic option value can be interpreted in two ways. First, it can be thought of as an individual's willingness to pay for the existence of an active insurance market. This leads directly into a theoretical framework for conceptualizing demand as well as an empirical demand analysis. If our hypothesis is correct, individuals at or near the poverty threshold should be more likely to purchase IBLI because their option value will be higher. Alternatively, the option value can be interpreted as the cost of making pastoralists as well off as they would be with insurance. This can be thought of as the certain cash transfer received in every period which makes a pastoralist as well off as they would be with actuarially fair insurance.