Dynamic Demand for Index-Based Livestock 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. 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.

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1 Introduction

Northern Kenya's arid and semi arid lands are home to more than 3 million pastoralist households. Among these households, the vast majority agree that drought is the largest issue that they face in terms of livestock mortality. Since these households depend primarily on livestock as their main livelihood, the risk of drought renders 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.

In January 2010 approximately 2,000 index-based livestock insurance (IBLI) contracts were sold in Marsabit District of northern Kenya. This paper proposes a theoretical dynamic demand analysis of the index based livestock insurance (IBLI) pilot in Marsabit district. We use dynamic programming techniques to generate an option value measure of the welfare gains attributable to the availability of IBLI for individuals with various levels of herd size.

In particular we analyze how herd size and IBLI together influence dynamically optimal behavior at or around a poverty threshold. There is growing evidence that permanent poverty traps exist in developing countries. Vulnerable households should have a higher option value for insurance if IBLI prevents such households from falling into a poverty trap from which there is no escape. If a higher option value exists, then we would expect to see evidence of higher demand for IBLI by individuals near a poverty threshold.

This paper is organized as follows. Section 2 provides a review of the related literature. To the authors' knowledge, no other paper to date has analyzed demand for index insurance (or welfare gains associated with index insurance) while explicitly accounting for poverty traps. In Section 3, we present a theoretical model of demand for index based livestock insurance in which we carefully account for herd dynamics and optimal decision making over time in the presence of a structural poverty trap. Section 4 describes our numerical implementation strategy including a method for constructing a dynamic option value for IBLI. In the remaining sections **??** and **??** we provide a discussion of the results of the numerical analysis including the optimal herd accumulation paths over time and the welfare gains attributable to IBLI. Our results suggest that the welfare gains from IBLI for a given household stem from two 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. Perhaps surprisingly, our results further suggest that vulnerable households have the most to gain from insurance, but they also have a lower willingness to pay.

2 Review of the Literature

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.

Many factors are likely to contribute to the existence of poverty traps; this paper focuses on uncertainty in livestock production. 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)

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 thresholds. Below the lower threshold herd size, 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. Hypotheses abound regarding asset smoothing and consumption smoothing as I described above, the biological capacity of livestock regarding both mortality and birth,[4] the lumpiness of the livestock investment,[5] the absence of credit markets, and the importance of risk aversion. Empirical evidence of the driving forces behind the dynamics remains fuzzy, and this paper chooses to set such questions aside by using a general form of a poverty trap without attempting to address the causes.

Regardless of the cause, it has been argued that a missing market for insurance amplifies the poverty trap phenomenon because households lack a safety net protecting against collapse. This market failure is the result of poor contract enforcement mechanisms, information asymmetries, high transaction costs, and covariate risk exposure. (Barnett, Barrett and Skees 2008)

In the presence of risk, such poverty traps create a tradeoff between helping the poorest of the poor versus preventing descents into poverty of a vulnerable population near a poverty threshold. Barrett, Carter and Ikegami (2008) use a stochastic dynamic programming model to show that threshold-targeted social protection programs which account for the poverty trap mechanism may help to eliminate needless poverty while boosting growth through endogenous asset accumulation and technology adoption. Their analysis indicates that such social

[4] 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.

[5] 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.

protection programs may be a much more effective (and economical) long run poverty alleviation strategy than traditional needs-based social relief policies.

Index-based risk transfer products are an example of threshold-based social protection programs because they serve as a safety net against descent to a low level equilibrium. Moreover, index-based products have many benefits over traditional insurance, including lower transaction costs and few asymmetric information problems which eliminate or greatly reduce moral hazard problems. They 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, 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.

It has been hypothesized that the main beneficiaries of index based livestock insurance in northern Kenya are not the poverty trapped households, but rather households that lie just above the poverty threshold. By modeling herd dynamics as a function of various stochastic processes, Chantarat, Mude, Barrett and Turvey (2010) simulate wealth/herd dynamics in Marsabit using rich panel and experimental data from the region. They demonstrate the existence of a threshold herd size, above which the herd will expand, and below which the herd will shrink.

Their 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.

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.

A critical limitation of the Chantarat et al. study is that it ignores behavioral choice, focusing instead on herd size as a state variable which follows a stochastic path to determine each household's future welfare path. Theoretical evidence suggests that perceptions of asset thresholds can induce a risk response (Lybbert and Barrett 2007 and Lybbert and Barrett 2010).[6] Furthermore, 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. This tendency to smooth assets is lost in the Chantarat et al. model where a pre-determined minimum level of consumption generates the dynamic bifurcation.

Ikegami, Barrett and Chantarat (2011) address this limitation by proposing another model of dynamic investment and purchasing decisions for IBLI. Their

[6] 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.

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. However, the scope of Ikegami et al. study is limited by the fact that the analysis fails to account for poverty traps. In particular, it excludes the possibility of heterogeneous option values due to the presence of poverty traps.

We expect that the presence of a safety net due to insurance may stimulate agents near the poverty threshold to further decrease 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 may, in effect, cause the implicit poverty threshold (commonly referred to in the literature as the "Micawber Threshold," below which agents tend toward a poverty trapped low level equilibrium) to shift in a way such that more households move toward the higher level equilibrium.

This paper supplements the Chantarat et al. (2010) and Ikegami et al. (2011) studies and 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 effect of IBLI and other similar products seeking to alleviate poverty. In the next section we discuss an analytical framework for accomplishing this task.

3 A Dynamic Model of IBLI

In this section we present a household model of index based livestock insurance in the presence of risk and poverty traps. We will then compare this "unconstrained" model to the case where the insurance market is absent. The model in that case will directly parallel the one presented here, except that the household does not have the choice of purchasing insurance as a consumption or asset smoothing tool.

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.[7]

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). Each herd produces a flow of benefits $f(H_t)$.[8] This flow function can be thought to encompass livestock births as well as flows such as milk products, which are the primary staple for people in this area.

Herd loss is dictated by a mortality function which depends on a random aggregate shock (θ_t),[9] which is realized for all households at the end of the period, and herd size in a given period (H_t). We assume the mortality function follows:

$$m(\theta_t, H_t) = \left(\frac{\min\{\theta_t, 0\}}{\underline{\theta}} \overline{m} + \underline{m} \right) H_t \tag{1}$$

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, so that limited rainfall (a more negative shock) results in higher mortality.

Households face a tradeoff between consumption today and investing in the

[7] 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.

[8] Following Dercon (1998) the flow function can also be thought of as a livestock production function. 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.

[9] We will eventually add an idiosyncratic shock. At this point, we assume no idiosyncratic risk for simplicity. In essence we are assuming no basis risk, an obviously unrealistic simplification.

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:

$$H_{t+1} = H_t + f(H_t) - m(\theta_t, H_t) - c_t \tag{2}$$

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 (which it is for every period). Similarly, the household can consume more than the flows. For example, the household could choose to slaughter part of the herd for consumption. If the household consumes all the flows and part of the herd this would be divestment. 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.[10] If the household chooses to purchase insurance then it must pay a premium equal to the price of insurance (p) times the number of TLU insured (I_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. This can be incorporated directly into the equation of motion for the herd:

$$H_{t+1} = H_t + f(H_t) - m(\theta_t, H_t) - c_t - pI_t + \delta_t(i_t(\theta_t))I_t \tag{4}$$

[10]In theory, the household can choose how many livestock to insure, but it cannot insure more livestock than they own. That is, the number of tropical livestock units (TLU) insured (I_t) must be less than or equal to the herd size (H_t):

$$I_t \leq H_t \tag{3}$$

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

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:

$$\delta_t = max\ ((i - s)V_L,\ 0) \tag{5}$$

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.

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 $H_t \leq \gamma_1$), growth is approximately constant for medium levels of herd size (i.e. for $\gamma_1 < H_t \leq \gamma_2$), and then positive growth is observed for large levels of herd size (i.e. for $H_t > \gamma_2$) (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 predominant 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.[11]

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 $\underline{f}$. We can now be more explicit in the structural form assumed for the production technologies:

$$f(H_t) = \begin{cases} \alpha H_t^{\gamma_L} + \underline{f} & \text{if } H_t \leq \hat{H} \\ \alpha H_t^{\gamma_H} & \text{if } H_t > \hat{H} \end{cases} \tag{6}$$

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) which 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. For completeness, we specify the following utility function which assumes constant relative risk aversion:

$$u_t(c_t) = \frac{c_t^{1-R} - 1}{1 - R} \tag{7}$$

where R is the coefficient of relative risk aversion.

The maximization problem at period 0 is characterized by the following

[11] 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.

equation subject to the equation of motion for herd dynamics (Equation 4) where β denotes the discount rate and $g(\theta_\tau)$ is the probability distribution of the covariate shock θ (which is the same for all households at time t):

$$V(H_0) = \max_{c_0>0,\ I_0\geq 0} \quad u_0(c_0) + \int_{t=1}^{\infty} \beta^t u_t(c_t)\ g(\theta_t)\ d\theta \tag{8}$$

This can also be written as the standard Bellman Equation:

$$V(H_t) = \max_{c_t>0,\ I_t\geq 0} \quad u_t(c_t) + \beta E[V(H_{t+1})] \tag{9}$$

The solution to this problem finds the optimal consumption and insurance decisions in each year t. In addition, the value function V can be used for welfare analysis in the presence and absence of an insurance market. Strategies for numerical implementation are discussed in the following section.

4 Numerical Implementation

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 leave to future research.

We assume a heterogenous population with identical preferences and uniformly distributed initial asset levels.[12] Parameters such as the prices and in-

[12]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 can be done using a panel dataset of household surveys conducted in Marsabit in 2009 and 2010. This data includes household level data on household and herd characteristics of 924 households. We leave this for future work, and instead use knowledge of the local situation to quasi-calibrate as best we can.

surance contract details (like the strike point and the value of a TLU) can be specified using observed values in Marsabit.[13] 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.[14] To gain intuition, we first assume the distribution of the index perfectly follows weather, so the model assumes perfect insurance. That is: $i_t(\theta_t) = m(\theta_t, H_t)$ and there is no basis risk. Table 1 shows the parameters used in the numerical simulation.

The solution to the problem outlined in the previous section 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. By applying value function iteration method to the Bellman equation of the agent's decision problem, we derive the optimal consumption and investment (in the herd) in the absence of an insurance market as well as an environment of "forced" insurance (such as where the government mandates full insurance). Ideally, we will also compare these results to the setting of optimal insurance choice, but for now we compare no insurance to the case where all individuals fully insure their herd. More specifically, we assume $I_t = H_t$ rather than $0 \leq I_t \leq H_t$

Comparing the value functions defined by the optimal choice 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

[13] 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.

[14] 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.

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 $z(H_t)$ 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:

$$V_I^*(H_t) = V_{NI}^*(H_t + z(H_t)) \tag{10}$$

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:

$$V_I^*(H_t - z(H_t)) = V_{NI}^*(H_t) \tag{11}$$

Note that equation 10 is essentially a compensating variation measure of welfare gains whereas equation 11 corresponds to the equivilent 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 can expect two things to hold. First, vulnerable households have the most to gain from the insurance safety net (they have a higher option value). This is because IBLI offers a safety net against total collapse, so that these households are now on a path toward a high level equilibrium, whereas without IBLI in the case of a drought they would be destined for the low level equilibrium. This means that vulnerable households will have a higher demand for IBLI because they value it more highly. Second, we would expect that IBLI will influence dynamically optimal behavior at or around a poverty threshold. For example, in the presence of IBLI, optimizing individuals just below the threshold might be willing to give up some consumption in the present in order to push themselves over the threshold. In essence, this causes the effective poverty threshold to shift because more households are able to reach the high level equilibrium.

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 IBLI. 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. This, in turn, can be compared to the markup price of insurance which makes the two value functions equal.

5 Optimal Herd Accumulation

Figures 2 and 3 demonstrate the mean herd accumulation paths over a large number of simulations for various levels of initial herd size under autarky and with insurance.[15] 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 (more on how we define vulnerability follows). 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 notable 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.

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

In contrast to the average herd accumulation paths observed in figures 2 and 3, figures 4 and 5 plot 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 6 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 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 figures 7 and 8 which plot the 10th, 25th, 50th, 75th and 90th percentiles of the terminal herd size across simulations under autarky and with IBLI respectively. 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 6 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. More generally, an insured herd is likely to reach a higher terminal herd size regardless of initial endowment than its uninsured counterpart. (Even the low level equilibrium is higher for insured households.)

6 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 9 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 a 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.

To make the option value more interpretable, we consider two scenarios. First, we look at the amount of cash transfer necessary in every period in order to make an uninsured household as well off as an insured household. (See figure 10.) Second, we'll consider the percentage of loading the insurance company could add over and above the actuarially fair insurance premium in order to bring an insured household to the same welfare level as an uninsured household. (See figure 11.)

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 necesary is highest for households that are trapped. The value declines as households become less vulnerable, and it is lowest for households who are unlikely to end up at a low level equilibrium.

In fact, we are interested in understanding the value of cash transfer necessary as it depends on vulnerability. Figure 12 depicts this relationship. As we would expect, the necessary amount of cash transfer is increasing as households become more vulnerable. This seems to support our hypothesis that vulnerable households will have more to gain from IBLI.

Figure 11 seems to tell a different story. The percentage of loading the insurance company could add over and above the actuarially fair insurance premium in order to bring an insured household to the same level of welfare as an uninsured household appears to be lowest for households near the poverty threshold. While the minimum willingness to pay for insurance is still high, (150% the actuarially fair price) it is clearly higher for households on either side of the unstable equilibrium. Similarly, figure 13 shows a decrease in the willingness to pay as vulnerability increases (ignoring for now the spike around 70%).

What does this mean? In the case of a markup, we are considering the increase in the price of insurance that decreases an insured household's welfare to the level achieved by an uninsured household. In a sense, we are taking something away from these households. This is in sharp contrast to the gift of a cash transfer. But note that vulnerable households do not have much income to give up. If they give up even a little bit, they increase their likelihood of collapsing to the low level equilibrium. That is, the marginal benefit of holding wealth in the form of livestock increases as the household's herd size approaches the lower bound threshold.

Essentially, we would expect that these households would not be willing to pay any amount that pushes them onto a path of decumulation (i.e. households will be unwilling to give up an amount that decreases their herd to a level that makes them 100% likely to move to the low level equilibrium). This combined with the cash transfer story seems to imply that vulnerable households have the most to gain from insurance, but because the marginal benefit of holding wealth in livestock is so high near the threshold, these household's will display a lower willingness to pay for insurance.

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. This project uses 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 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 analyzing different types of welfare measures we find that vulnerable households have the most to gain from insurance, but are the least likely to be able to afford it.

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 issue.

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Appendix

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
β = 0.95 R = 1.5
Insurance Contract Parameters
p=.0325 s=.15 V_L=15,000
Random Shock
θ={-20,-10,0} $g(\theta)$={.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

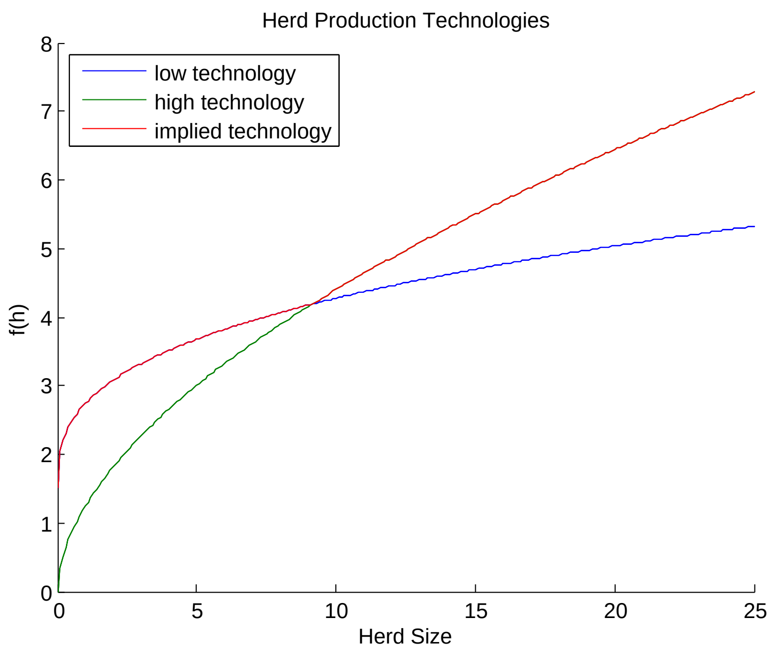

Figure 2: Mean herd accumulation paths under autarky for various initial herd sizes

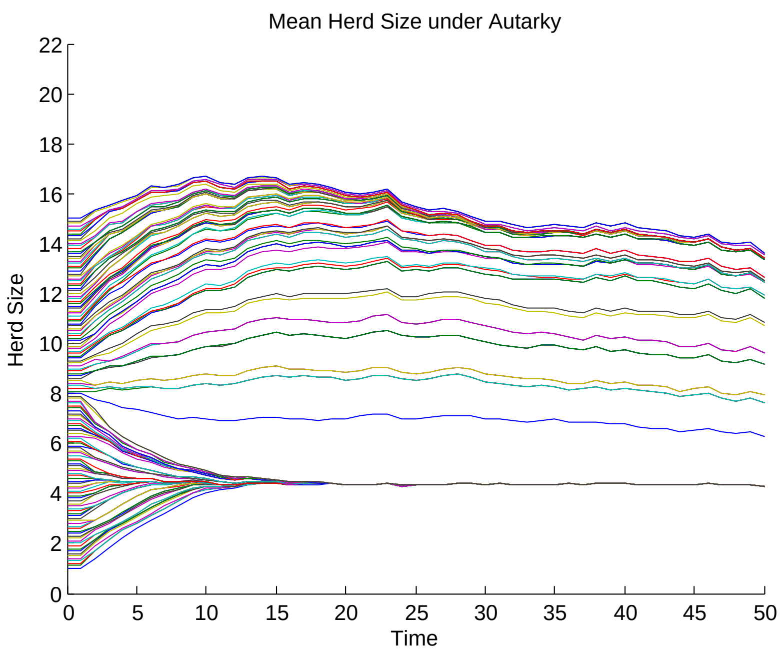

Figure 3: Mean herd accumulation paths under full index-based livestock insurance for various initial herd sizes

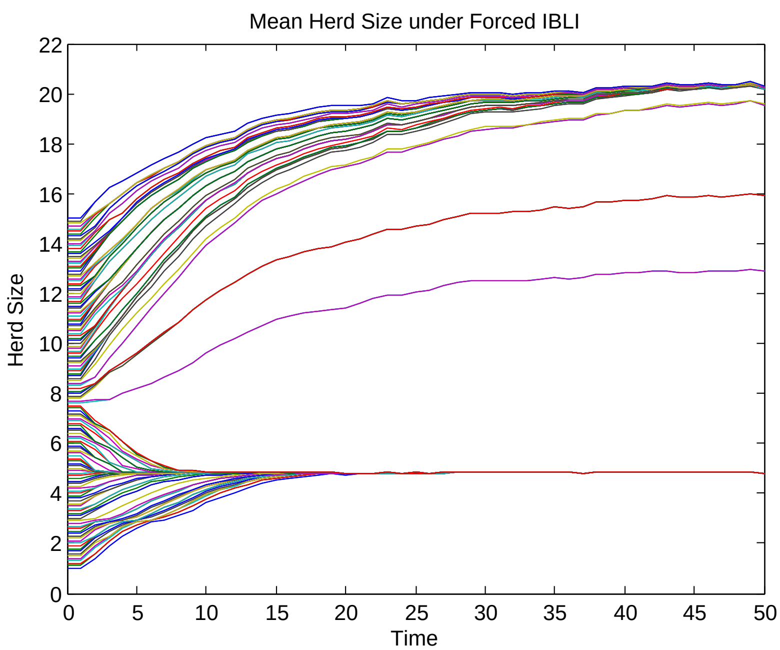

Figure 4: Median herd accumulation paths under autarky for various initial herd sizes

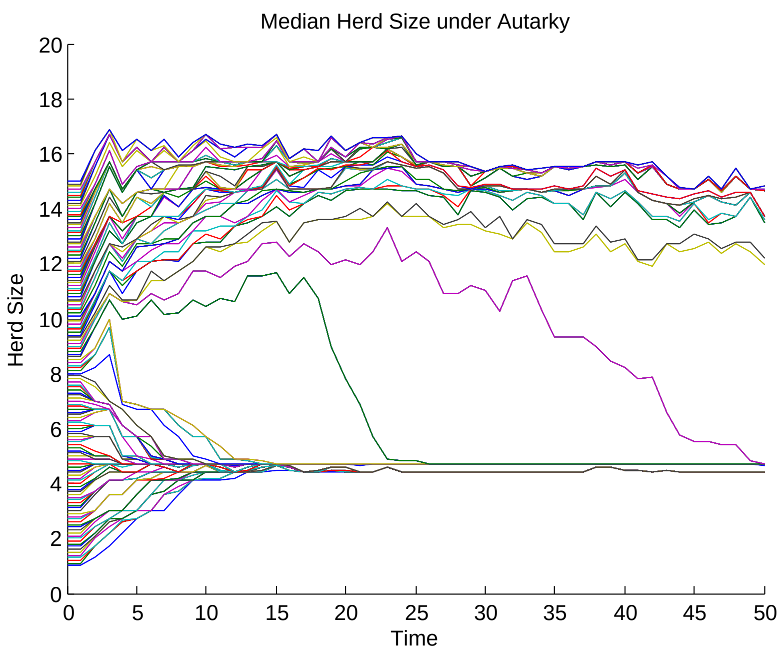

Figure 5: Median herd accumulation paths under full index-based livestock insurance for various initial herd sizes

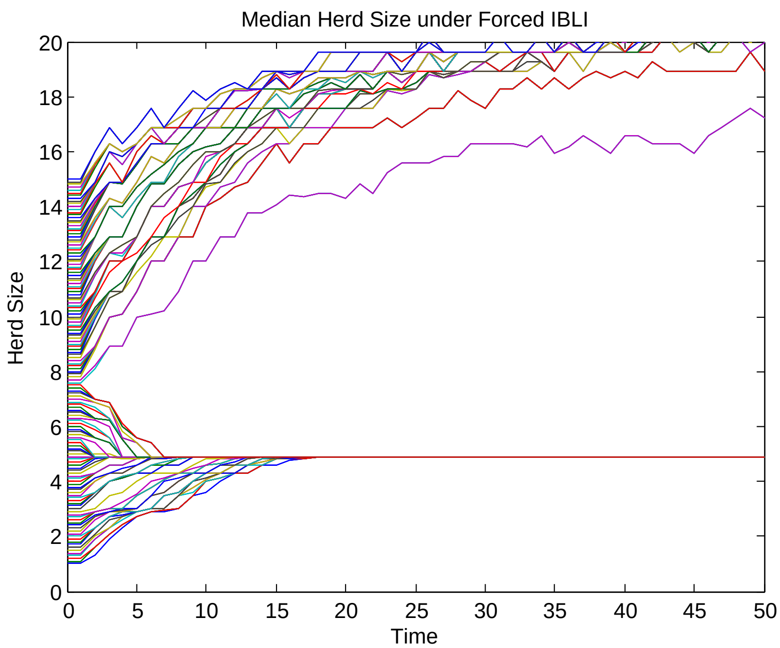

Figure 6: Probability of Collapse to a low level equilibrium with and without IBLI

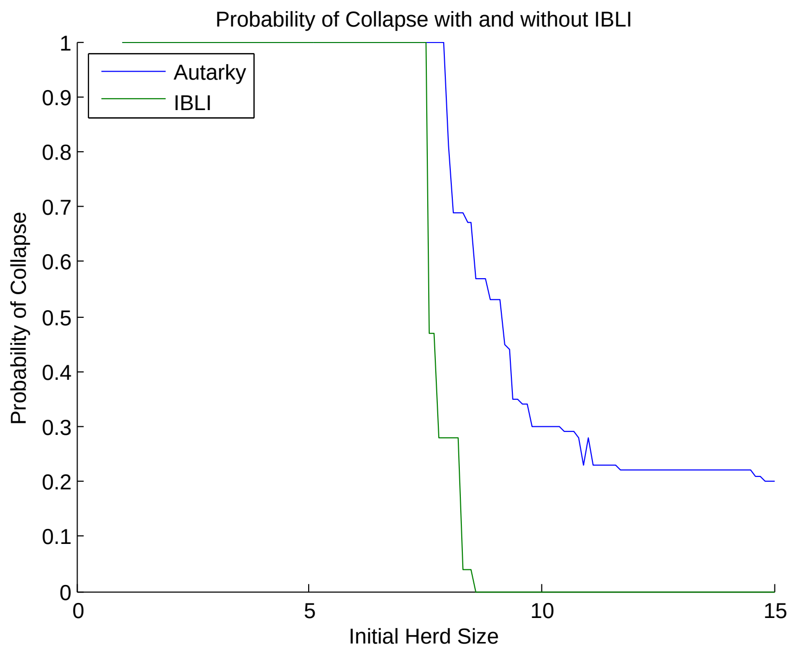

Figure 7: Herd Transition under Autarky: Initial to Terminal

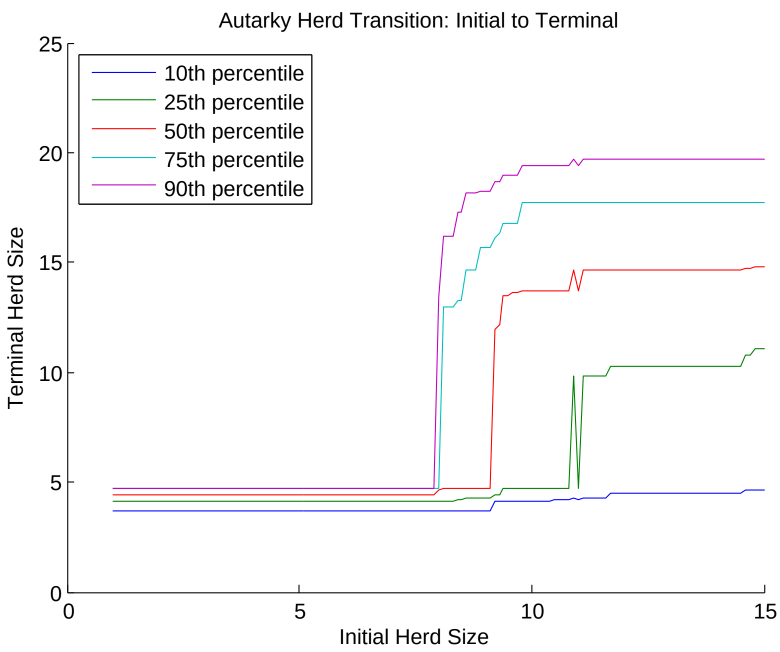

Figure 8: Herd Transition with IBLI: Initial to Terminal

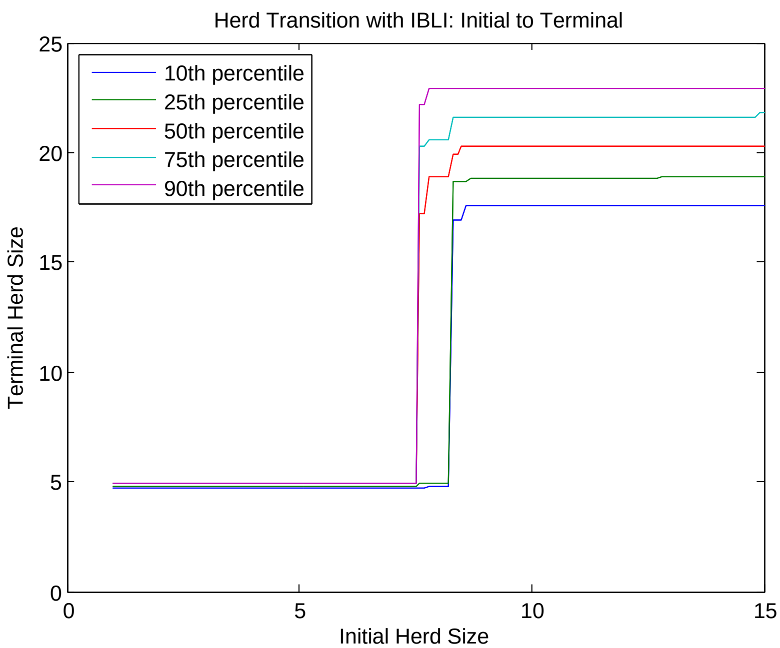

Figure 9: Dynamic Option Value

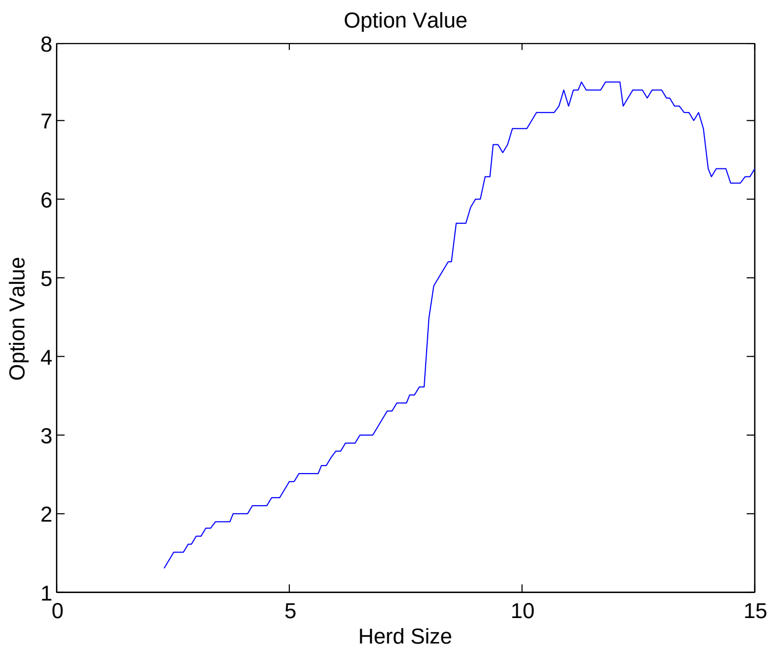

Figure 10: Amount of cash transfer necessary in every period to make an uninsured household as well off as an insured household

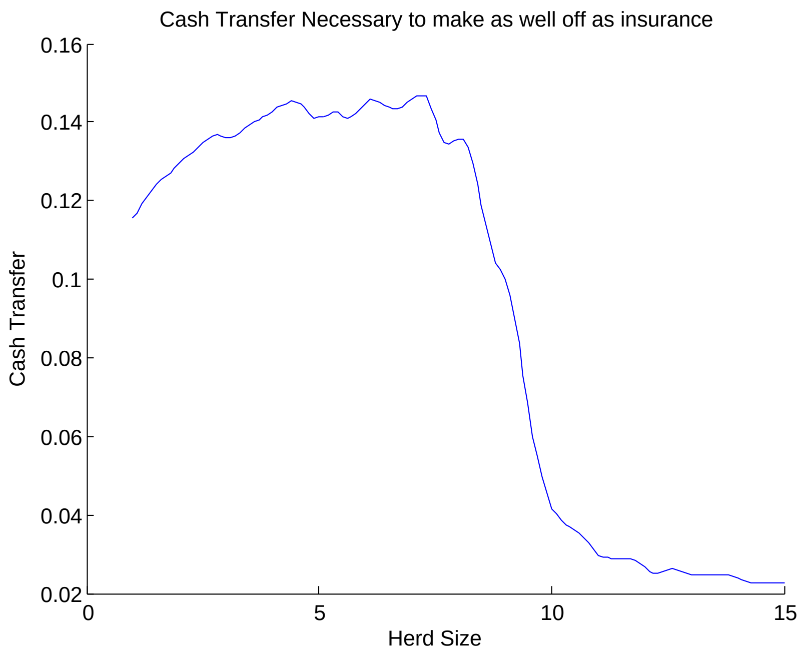

Figure 11: Willingness to Pay for IBLI as a percentage of the actuarially fair price

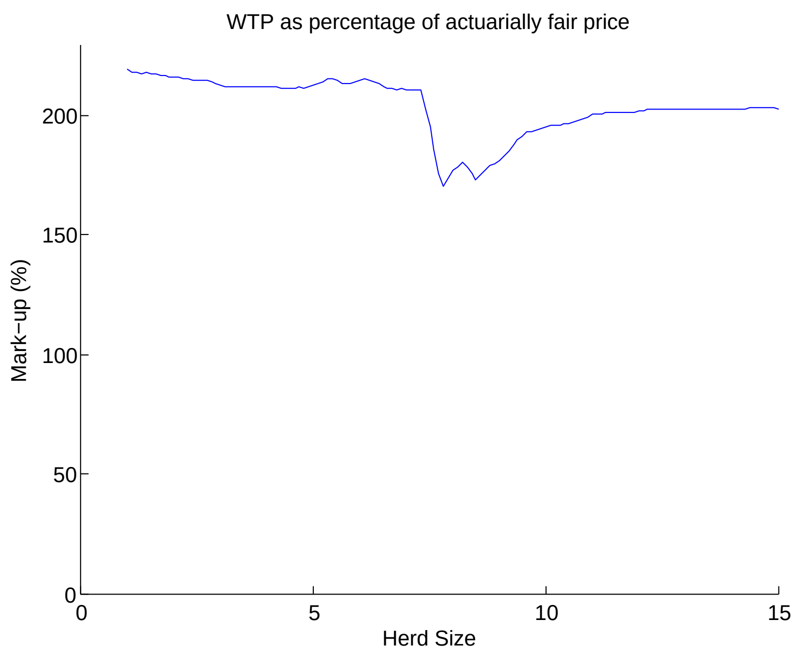

Figure 12: The relationship between vulnerability and the cash transfer necessary in every period to make an uninsured household as well off as an insured household

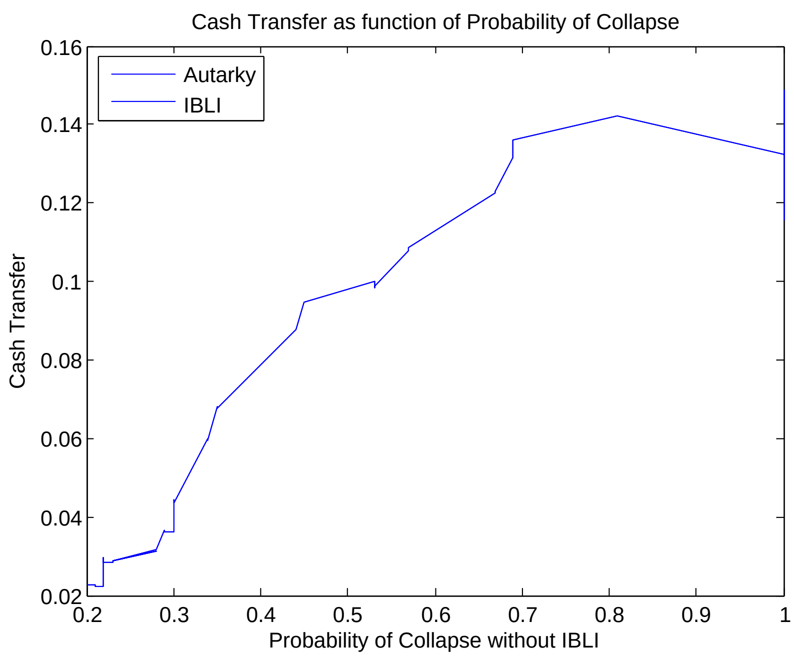

Figure 13: The relationship between vulnerability and willingness to pay for IBLI as a percentage of the actuarially fair price