Paper V

Reducing climate risk for micro-insurance providers in Africa: a case study of Ethiopia

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Abstract

Recurrent climate hazards challenge subsistence farmers in developing countries. Reliance on various diversification strategies and traditional risk sharing among kin and families has serious limitations, such as the problem of covariate risk within such networks. Index-based crop insurance could help to reduce people's climate-related risk, but raising the necessary capital to make insurance schemes financially secure is difficult for micro-insurance providers. We examine the extent to which spatial pooling of micro-insurance schemes could reduce these capital requirements. We simulate an insurance market operating in Ethiopia, using rainfall data and yield estimates for fifteen stations. By performing a Monte Carlo analysis, risk capital required to keep the probability of financial ruin below a threshold value is identified. We investigate the marginal benefits of pooling increasing numbers of sites, as well as the relationship between the benefits of pooling and the spatial covariance of rainfall. We find spatial diversification to offer considerable savings in required capitalization with as few as three sites pooled, as well as a weak but significant relationship between rainfall covariance and those benefits. The results suggest that spatial pooling may be an attractive option for micro-insurers, worthy of a detailed case-by-case analysis when designing index insurance schemes.

Key words

Spatial diversification, Ethiopia, climate insurance, climate adaptation

1 Introduction

A critical challenge for sub-Saharan Africa is high spatial and inter-annual rainfall variability, presently and in the years to come due to anthropogenic climate change (McCarthy et al., 2001; UNDP, 2000). Rural livelihoods, which in many regions are based on subsistence and rainfed farming or pastoralism, are especially vulnerable to variation in climate, changes in that variability, as well as to climatic extremes (Boko et al. 2007). The economies of most African countries are highly dependent on agriculture, the economic sector that is arguably most sensitive to climate variability and change (Antle, 1995). A single drought may threaten the lives of many individuals, and risk-management, formal and informal, becomes crucial for survival. the majority of African countries are in the lowest group in the United Nations Human Development Index rankings (Watkins, 2005). This poverty indicates that many people are at the edge of survival, and will suffer not just lost of income but also loss of health, or even life, as a result of climate disruptions (Brooks and Adger, 2004; Yohe and Tol, 2002). It also means that fewer resources are available to adapt to climatic factors (Adger et al., 2003). Scholars have suggested that coping with climate variability may be, now, the best way to prepare for climate change (Patt et al., 2007; Washington et al., 2006).

Traditional survival strategies applied to climate hazards like drought are often very varied and diversified (Scoones et al., 1996) , and include methods for spreading risk throughout a community, taking advantage of kin relationships and social capital (Klopper et al., 2006; Roncoli et al., 2001). These coping strategies, however, are challenged by extreme events that threaten an entire community simultaneously, or which occur in successive years, draining a family's own capital reserves, usually in the form of livestock (White et al., 2005). The alternative to informal risk spreading mechanisms is the use of insurance, by which a third party assumes some of the risks associated with climate variability, and is able to draw on financial reserves. Micro-insurance schemes can be considered as an option for poor households to better adapt to such hazards (Osgood and Warren, 2007). A variety of institutional forms of climate insurance schemes exist or are possible, ranging from independent initiatives of microinsurance to partnerships with other institutions of the donor community (Linneroth-Bayer and Mechler, 2006). Climate insurance, compared to ex post humanitarian relief, is also seen as preferable in the context of climate change adaptation, since it sends clear market signals concerning the level of risk, and can thereby steer new infrastructure investments into places and forms that make sense under conditions of global change (Gurenko, 2004). So far, however, private financial institutions have played only a small role in contributing to the reduction of risk for household asset depletion and famine as a consequence of climatic hazards in Africa. The one scheme that currently does exist, in a pilot stage, serves only a few thousand farmers in Malawi (Osgood and Warren, 2007).

There are several challenges for the development of insurance markets serving the poor in sub-Saharan Africa, not least of which is access to sufficient risk capital reserves to make sure that insurance companies remain solvent (Hochrainer et al. 2007). On average, the insurance premiums should be sufficient to cover the cost of risk, but in bad years, the insurance company will need access to sufficient capital reserves to settle claims. In typical markets, a small insurance company provides policies over a relatively small geographical area. To achieve spatial diversification of risk, such insurance companies purchase reinsurance. However, there is reason to believe that the profit margins on reinsurance contracts are very high, raising the cost of supplying the primary insurance, and putting the entire business out of reach of poor farmers in Africa. In this paper, we explore the benefits of a different means of reducing the need for backup capitcal, namely through pooling across a larger geographical area, such that the climate risks are not perfectly correlated. We examine, through the use of spatially explicit Monte Carlo simulation, how the requirements for backup risk capital change, as several regions within a single country are pooled together. We test the model using data from Ethiopia, a country characterized by recurrent drought and chronically food-deficiency as a combination of climatic, institutional, environmental and factors like population growth. Moreover, Ethiopia is well suited for this study as a number of different climates from very dry to humid are represented, thus providing the environments for possible non-correlated climate regimes.

2 Background

African smallholder farmers have a number of strategies to cope with climate variability and extreme events, such as drought (Scoones et al., 1996). First, they accumulate capital, often in the form of livestock, which they can sell in times of need. Second, they engage in alternative activities, such as handicraft production, which can generate income independent of rains. Third, they diversify their farming techniques, allowing some farming income in all but the worst of years. Fourth, they engage in informal risk spreading across kin and social networks, helping each other out when individual families face difficult circumstances (Meze-Hausken, 2000). In the last several decades, however, recurring droughts along with population explosion and slow economic growth have challenged farmers' ability to accumulate capital as a form of savings, or to earn money through alternative means (Bromley and Chavas, 1989). Informal risk sharing does not work when an entire community is hit by one or multiple years of drought. Moreover, these strategies come at a significant cost. For example, diversifying their farming activities, such as planting low yield seed varieties because of their drought tolerance, often means engaging in activities that are less productive, but which hedge risk. While engaging in low-risk, low yield farming lessens their exposure to extreme events, the over-diversification of their income sources keeps farmers from taking advantage of profitable opportunities (Linneroth-Bayer and Mechler, 2006).

2.1 Index-based micro-insurance

Given these issues, an increasing number of organizations are proposing the idea of micro-insurance, supplementing micro-finance, as a way to help rural Africans manage those risks that their traditional methods cannot handle. International organizations such as the World Bank and the World Food Program, donor agencies such as the Untied Kingdom's Department for International Development (DFID) and Germany's Organization for Technical Cooperation (GTZ), and non-governmental organizations (NGOs) such as Germanwatch and Oxfam, have been engaging major insurance and re-insurance companies, such as Munich Re, Swiss, Re, and Allianze, in discussions about how best to extent insurance coverage to the poor in Africa (Bals et al., 2006; Hess and Sykora, 2005; Hoeppe and Gurenko, 2006; Linnerooth-Bayer et al. 2005; Linneroth-Bayer and Mechler, 2006). Such a process has been underway for the last decade in India, where micro-insurance is now widespread, but faces the hurdle of even deeper poverty in Africa.

Crop insurances against weather anomalies are a long-established mean of risk management, with first experiences as far back as the 1880s in the United States, when companies began to offer coverage to tobacco farmers against loss from hail. Traditionally, insurers have been paying claims that were assessed based on individual losses, so called indemnity based insurance (Mechler et al., 2006). Due to the high costs of claim settling resulting from indemnity-based insurance relative to the values insured in developing countries, index-based schemes have become increasingly used for smallholder farmers. For the latter, contracts are written against a physical trigger, such as rainfall measured at a local station. In addition to reducing the cost of settling claims, index-based insurance also reduces the problem of moral hazard, which refers to the incentive people have to engage in riskier activity because they have the insurance; since the payouts are not coupled with individual losses, farmers have an incentive to salvage whatever value they can from their own fields, as this will not reduce their insurance payout. Index-based insurance can either operate as a stand-alone contract, or can be linked directly to a loan, such as for buying seeds. The latter type of contract and insures the payback of the loan, rather than directly the harvest failure, and can enhance the credit-worthiness of the farmers.

2.2 Pilot insurance schemes in Africa

In Malawi, a packaged loan and index-based insurance product was implemented in 2005, with technical assistance from the World Bank and an NGO, Opportunity International (Hochrainer et al. 2007). This was the first micro-insurance offered to farmers in Africa, and was especially attractive because it allowed farmers to borrow money to purchase a high yield variety of groundnut seed that they would not otherwise have been able to afford. The increased yield, on average, from this seed variety was calculated to more than compensate for the cost of the insurance, and it represented a win-win situation. The trigger for payouts was based on a water requirement satisfaction index (WRSI), as a weighted sum of cumulative rainfall during the 130-day growing period, with individual weights assigned to dekadal (10-day) rainfall totals (Hess and Sykora, 2005). The payout triggers were based on robust data on the groundnut development, such that the payout was thought to match the actual losses that farmers would incur quite closely. This minimized their so-called “basis risk,” the risk that insurance payouts would not match their actual losses. The interest rate of the loan included the premium for the weather insurance, totalling 9.9% of the value of the loan, paid from the bank to a national insurance association. Approximately 3,000 farmers participated in the program in its first two years.

The Malawi scheme illustrates the benefits of linking formalized insurance as a risk-reduction strategy to a credit scheme. The result is that farmers can focus their production activities on higher value-added products, with the insurance reducing the risk associated with such specialization. (Bromley and Chavas, 1989). It could enable farmers to invest in more appropriate seeds, irrigation, and other means of increasing their productivity, leading to greater accumulation of assets for bad rainfall years to come. This could strengthen drought resilience indirectly, even though the insurance scheme does not itself provide a complete safety net in years of poor harvests.

A very different kind of insurance program has been used in Ethiopia, although it is similar to the Malawi system insofar as payouts are based on the WRSI. In Ethiopia, the World Food Programme (WFP) purchased US$ 9 million in coverage from a large European provider, Axa, to cover their humanitarian relief activities, paying a premium of over US$ 1 million. The coverage was matched to the costs WFP expected that it would have to incur in the case of a drought, and so allowed WFP to plan for relief activities for up to 17 million people at a scale larger than its own financial reserves would have allowed (WFP, 2007).

2.3 Capital costs

Like all insurance contracts, the premiums for micro-insurance are the sum of four different types of costs. The first are the actual risk costs, namely the average payout over several years. The second are "frictional" costs associated with providing insurance, such as the analysis of the underlying risk, including data gathering, and marketing costs. The third are capital costs, namely the opportunity cost of having enough liquidity available to cover all claims that might arise, either on-hand or through a separate reinsurance contract. The fourth are the profits that the insurance company earns its investors. The ratio between the total premium price and the risk costs is known as the loading factor. A loading factor of 2, for example, would mean that half of the premium price was covering the risk costs, and the other half covering the other three kinds of costs. In large highly competitive insurance markets for non-correlated risks (e.g. automobile insurance), loading factors are quite small. In highly specialized insurance markets, loading factors can exceed 10. Loading factors are often quite high for reinsurance, in part because the market is not very competitive.

There are two main challenges for providing insurance to the poor in developing countries. The first challenge is keeping the cost of the insurance low enough to be affordable, i.e. reducing the loading factors as close as possible to 1. This is especially difficult because the frictional costs are often quite high, even as the insured values are quite low. Two solutions to this problem are the use of index-based systems, which reduces these costs substantially, and to make use of technical support from donor agencies at zero cost. The second challenge is obtaining enough backup capital to cover potential claims. Purchasing reinsurance could alleviate this problem, but it would drive up the capital costs enormously, and potentially make the premium unaffordable. Any mechanism that could reduce the amount of backup capital needed to be kept liquid would address this second challenge, and would also serve to lower the capital costs, and hence the premiums (Gurenko, 2004).

The capital cost problem is particularly acute for index-based insurance. Insurance markets are often surprisingly local, both because of the need to understand and assess local conditions, and because the industry is highly regulated. For index-based insurance this represents a problem, because a local insurance company will have to pay out premiums all at once, or not at all. Indeed, the risk of illiquidity is quite high for locally specific micro-insurance projects, such as the one in Malawi (Hochrainer et al., 2007). While institutional factors may preclude spatial diversification at a continental scale, it is conceivable that a single insurance company could offer similar types of micro-insurance across different locations in the same country. While this may be common practice in industrialized countries (Castaldi, 2004), it has not yet happened in Africa.

Diversification across uncorrelated risk can reduce the amount of capital that is necessary to make an insurance program sustainable. It is common for minimum risk capital holdings to be regulated by law, or established by ratings agencies. But these minimum capital requirements are thought often to be insufficient (Swiss Re, 1996), and ultimately the responsibility falls on the insurer itself to determine if capital is sufficient. In the case of Africa, donors want to be sure that programs they start will be sustainable, and will not require additional cash infusions if several years of high claims occur in succession.

A critical question, then, is the extent to which risks within a single African country are uncorrelated enough to generate a portfolio of policies covering the same type of risk (e.g. drought) with lower aggregate risk capital requirements. Because of the complicated nature of index-insurance contracts, analyzing this requires a simulation model that takes into account spatial correlations in the underlying risk factor—rainfall—as it examines the risk capital requirements to keep the insurance company solvent. In the following section, we present a model that does this, answering three questions: First, in a typical African context, how much less capital, as a percentage of total insured value, would be required if spatial diversification were taking place? Second, what are the relative marginal benefits of pooling two different regions and adding additional regions? Third, how much do the savings in risk capital depend on the precise correlation in rainfall between the different sites?

3 Methods

In this section, we describe a simple Monte Carlo simulation model to simulate an insurance market based on historical rainfall and crop yield data. We develop the model for the country of Ethiopia, for two reasons. First, Ethiopia is a country where the problem of droughts affecting rural livelihoods is acute. During the 20th century Ethiopia experienced 18 droughts of which eight affected the whole country and the other 10 regions or local levels, covering 40 years

(Meze-Hausken, 2000). More than 90% of the annual agricultural production is provided by the *meher* harvest, fed by the summer rains. With 85% of its population engaged in subsistence agriculture, where agriculture is a mixture of cropping and livestock management, there is a continuing concern for food production. Second, Ethiopia is a country with enough spatial diversity in rainfall patterns—both in terms of average rainfall at each location, and the responses of local rainfall to external forcing factors—to generate interesting results.

3.1 Data and crop yield functions

Ethiopia is divided into six climatic zones, as shown in Figure 1. We obtained annual Ethiopian precipitation time-series from the Climatic Research Unit at the University of East Anglia. The 15 stations are those with long-term records, and cover the different zones. Only one station is located in a pastoralist zone, with annual rainfall well below 600 mm, while the remainder are in agricultural zones. The rainfall series comprises a maximum of 52 years, with the time-span starting in 1951 until 2002, although many individual years' data are missing from many of the stations. Table 1 lists the 15 stations, the zone within each falls, and key features of the data.

[Figure 1 and Table 1 about here]

At least one of the staple crops maize, wheat, barley, teff and sorghum are grown in each zone, with many farmers in some zones growing several crops. We obtained information on the crop varieties and mean yields for each site/region from Food and Agricultural Organization (FAO) data, as reported in (Velthuizen and Verelst, 1995). From the mean yields of each staple crop at each location, we constructed linear functions predicting yields based on annual rainfall. At each location and for each crop, we assume a yield of 0 if annual rainfall is below 400 mm, with a linear function from there that crosses the intersection of average location specific rainfall and average location and crop specific yields.

There are several limitations to the data we were able to work with, and the yield functions that we developed from these data. Most importantly, actual crop yields vary not as a function of annual rainfall, the data we obtained, but rather much more closely with dekadal (ten day) rainfall totals within the growing season for each crop. Second, the crop data we were able to access did not contain detailed descriptions of the relationship between actual rainfall and yields, but rather indicated average yields for each staple crop at each location. Third, the data did not indicate the relative proportions of crops grown at each location, but rather those crops that are grown at all. For these three reasons, the yield functions that we developed are crude, and contain numerous simplifying assumptions, such as that equal quantities of the different staple crops are grown at each station. Our functions would thus do a poor job predicting actual yields at each location; to do so more accurately, far more detailed data would be required. These limitations are not fatal to our analysis, however, because we are interested in illustrative relative yields across years and locations, and the results that we obtain provide an accurate enough picture to gain insights in the effects of rainfall correlation.

3.2 Simulation model

We use the data and yield functions in a Monte Carlo model that simulates a series of 30 consecutive years, and than repeats that simulation many (e.g. 10,000) times in order to obtain distributions of key parameters. Figure 2 shows the basic model structure, which tracks that of an index-based micro-insurance market. The insurance company manages to raise a certain amount of backup risk capital, and augments or draws from that capital each year based on the difference between premiums collected and claims paid out. The premiums are calculated for each site based on expected payouts times a loading factor. Payouts in turn are calculated for each year at each site based on yields. If yields, which depend on rainfall, are above an upper threshold, there is no payout. If the yields are below a lower threshold, there is a payout of the full insured value. In between the two thresholds there is a linearly calculated partial payout. At each site, the two thresholds are negotiated locally so as to ensure that the premiums remain affordable, between 5% and 10% of the insured value. As an example, the Awassa region, with mean annual rainfall of 925 mm (1971-00) and annual yield of between 0.4 tonnes/hectare (t/ha) for wheat and 0.2 t/ha for teff and maize (the three crop types grown there), and thus a mean average yield of 0.267 t/ha. The upper threshold (no payout) was set at 0.2 t/ha, and a lower threshold (full payout) at 0.1 t/ha, which corresponds to rainfall amounts of 772 mm and 586 mm respectively. Based on the distribution of rainfall observed since 1950, this results in an average payout that is 6% of the total insured value. A loading factor above 1 would increase the premium above this amount, and in our simulations we used a very small loading factor of 1.1. Three locations— Mekelle, Jijigga, and Dire Dawa —have exceptionally low rainfall and yields, and realistic thresholds resulted in premiums exceeding 20% of the insured value. These are places where farming cannot generate sustainable livelihoods, and government or donor support would be required to make the insurance affordable, much as it is currently necessary to ensure people’s survival.

[Figure 2 about here]

The key parameter is the amount of capital that the insurance company has at any one time. For each run of 30 years, the model calculates the minimum initial capital necessary in order to maintain solvency over the 30-year duration. The model allows us to specify the degree of pooling capital accounts; for example, we can specify that different insurance companies, with separate capital accounts, cover each site, or that a single insurance company, with a single capital account, covers all 15 sites. The model assumes that the total insured value is equal at all sites. The model calculates the starting capital required in relation to the total insured value covered by the particular insurance company, or collection of insurance companies. With many runs of the basic model in a Monte Carlo simulation, it can provide a probability distribution of the initial capital requirements under the different pooling specifications. From that distribution, we selected the initial capital requirement required to maintain solvency in 95% of the model runs, as a useful point of comparison.

The random component in the model, allowing for a Monte Carlo simulation of the distribution of capital requirements, is annual rainfall. To simulate rainfall at all of the sites while maintaining spatial correlation, the model randomly selects a data year (e.g. 1983) from the available set. The model then applies the amount of rain observed at each location during that data year. To cope with missing rainfall observations in the data set, the model nullifies insurance contracts at those locations where data was missing in the year selected, and refunds farmers the full amount of their premiums, while maintaining the insurance contracts at the remaining locations. In this way we were able to make maximum use of the data that we did have, since there are very few years for which all sites provided data. After calculating premiums, payouts, and changes in capital accounts, the model then selects another random data year (e.g. 1957). This process repeats 30 times, to simulate 30 consecutive years. While this methods preserves spatial correlation, it does assume independence across consecutive years, which is not entirely accurate, although less important that spatial correlation for our purposes. The only alternative that we know that would preserve both spatial and temporal dependence would be to repetitively simulate a 30 year time series for Ethiopia using a regional climate model, using distributions of starting parameter values. This is beyond our modelling capacity.

[Figure 3 about here]

We verified the model by calculating premiums and payouts for the period 1951 – 2002. Historical rainfall data indicate that 31 years would have had a mean payout for *all* stations in the order of under 9%, while 7 years would have had between 20 and 29 percent. In 1984, the worst year in the time series in terms of total rainfall, generated mean payouts of about 45 percent of the insured value of all stations. Figure 3 gives an overview of the potential payouts as a mean for all stations for the last 50 years. While there is no apparent trend towards increase or reduction in payouts over time, it appears that, occasionally, years with higher payouts re-occur over several years. However, the assumption of independence across years that we assumed in the Monte Carlo simulation does not seem entirely inappropriate, as there is no clearly visible pattern of temporal autocorrelation.

4 Results

Figure 4 shows the basic results from Monte Carlo simulations with four different levels of aggregation of insurance schemes. It plots the amount of starting capital required to avoid insolvency in 95% of the model runs, i.e. to avoid insolvency with probability 0.95. Under the least aggregated system, there would be 15 different insurance companies operating, each covering a single location. As is evidence from the very light grey curve, the amount of capital required at the least drought-prone site is about 40% of that site's total insured value, while the at the most drought-prone site it is about 350% of that site's total insured value. Approximately half of the sites could get by with 90% or less of total insured value as their initial capital, in order to avoid insolvency with probability 0.95. At the other extreme, the black curve shows the situation when there is a single insurance company covering all 15 sites. Because of the benefits of sharing the risk, it can avoid insolvency with probability 0.95 by raising initial capital equal to about 40% of the total insured value. It is an artefact of these data that this coincides almost exactly with the capital requirements of the least drought-prone site, when the sites were considered separately.

[Figure 4 about here]

The two intermediate curves show all of the possible combinations of sites, when they are pooled either into groups of two sites or three sites. There are 105 possible combinations of two sites, and 455 possible combinations of three sites. In the case of two sites pooled, there is a single combination of the two most drought-prone sites that requires initial capital in excess of 300% of the insured value for these two sites. In general, however, both the two-site and three-site curves lie to the left of the lightest grey curve, and to the right of the black curve, indicating that partial pooling captures some but not all of the benefits of pooling. The exception is at the bottom left hand of the figure, where both of the partial pooling curves cross the black curve. There are a few combinations of two or three sites with a low risk of drought, for which the initial capital requirements are very low. These pooling schemes capture the benefits both of several individual sites' low risk, and of pooling across sites where rainfall is not perfectly correlated.

[Table 2 about here]

How great is the latter of these two benefits? Table 2 shows a selection of three-site combinations, and indicates the savings in initial capital requirements when the sites are pooled, compared to when they are insured separately. The greatest savings we observed was 35% at the combination of Goba, Addis, and Gonder, where the capital required was 0.65 of that required if the three sites were insured under separate schemes. The minimum savings we observed was 3%. Clearly, these savings would be related to the degree of correlation in rainfall between the different sites, with pooling arrangements for sites with the least correlation in rainfall generating the greatest benefits. To examine this in the simplest case—pooling schemes for two sites—we constructed a matrix of correlations between pairs of sites. Figure 5 shows how the different sites rainfall correlates, with the lighter lines connecting sites indicating strong positive correlation, and the darker lines indicating negative correlation.

[Figures 5 and 6 about here]

Figure 6 indicates the relationship between the correlation in rainfall between two sites, and the savings in the initial capital requirements, again to ensure solvency in 95% of the model runs. The dots cover all of the possible pairings of two sites, and show that sites that are more negatively correlated generate greater savings in capital costs when pooled. We conducted an ordinary least squares regression of the Y-axis values—the ratio of pooled to unpooled capital requirements—on the correlation coefficients, obtaining an R^2 of 0.25, and a regression line significantly different from zero (*student's* $t = 5.86$, $P < 0.001$). What this indicates that that the correlation coefficient between two sites is a significant predictor of the savings of capital costs, but is not specific enough a descriptor of the relationship between different sites' rainfall to capture more than a quarter of the variance in capital cost savings: simply looking at the correlation coefficient is not a shortcut to avoid more detailed modelling.

5 Discussion

Our model has yielded three main results. First, and most importantly, it has shown that significant savings in capital requirements can be obtained by pooling insurance schemes within a single country. Pooling takes advantage of less than complete correlation in rainfall between different sites, and offers benefits even when only two sites are pooled. Given the structure of the model and the data we obtained from Ethiopia, pooling all sites reduced the ratio of required capital to insured value to be about equal to the ratio observed at the least drought-prone site. The second result, completely expected, is that there is a strong relationship between the correlation in rainfall between different sites and the savings that can be obtained from pooling: the more negative the correlation, the greater the savings. The third result is that simply calculating the correlation in rainfall between different sites is not enough to predict the savings in capital requirements with a high degree of accuracy. Instead, one has to engage in the full modelling effort.

There are several important limitations to our modelling approach, although we do not believe that these are fatal to the three main results. First, both the rainfall and crop yield data upon which we have built our model are highly aggregated, meaning that the predictions of yields that our model makes are probably not very accurate. In designing an actual insurance index-based system, such as the one in Malawi, one would need access to finer data, such as dekadal rainfall and more specific relationships between rainfall over the course of the growing season, and crop yields. Second, the payoff functions and premiums that we have built into our model are also highly simplified. These will be locally determined based on better information about what farmers can afford to pay, and how the insurance scheme fits into farming activities more generally: whether, for example, it is tied specifically to loans for seed. Again, in designing an actual system, one would need this kind of detailed information. The third limitation is our assumption of independence between years. Resolving this problem would, we believe, require making use of a regional climate model, which increases the modelling challenge significantly. Our results may change to some extent should all of these limitations be addressed, but we see no reason why the basic qualitative messages would be different. While there may be an infinite number of possible combinations in model assumptions when applying an "if-then" analysis (Ermolieva et al. 2003), which relates in our study to selected threshold levels, yield-functions, and loading factor, the model as presented here nevertheless gives a first order estimate of how various policy alternatives may affect the robustness of a micro-insurance scheme based on the regional climatology, and suggests that the substantial work required to design an actual insurance pooling scheme may be justified.

There are two issues that we have not addressed, and which ought to be the basis for continued work in this area. First, we have not examined at all the individuals' willingness to accept a certain premium level. This is an empirical question. For example, a case study of pistachio farmers in Iran revealed that farmers were only willing to pay, on average, premiums equal to 73% of the actual expected losses (Ezzatabadi, 2006). In such a case, then, any insurance system would require substantial state or donor subsidies in order to be sustainable. Even in countries like the US, Gardner and Kramer (2004) conclude that premiums would have to be subsidized as much as 50% to achieve 50% participation in a climate insurance scheme for farmers. Even if farmers are willing to pay the full risk-cost of insurance, it may still well be that donor support is required to cover other elements of the premium price, such as the fixed "frictional" costs associated with analysis and marketing, or the capital costs (Linneroth-Bayer and Mechler, 2006). Second, we have not included the issue of longer-term climate change in our analysis, but rather assumed that rainfall over the next 30 years will be roughly similar to that over the last 50. This is an issue for modelling. Hochrainer et al. (2007) examined this issue for the Malawi pilot insurance scheme, and found that climate change roughly doubled the capital requirements.

While spatial pooling of the risk has been a well-established practice in industrialised countries, such schemes have not been implemented in developing countries. The model has clearly shown possible advantages of aggregating and optimising regions spatially as well as spreading the losses on a regional level, and suggests that undertaking detailed analysis of the benefits of pooling, at the time of setting up actual micro-insurance systems, would be effort well spent.

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Figure Captions

Figure 1—Map of Ethiopia showing rainfall zones. Zone A has one short rainy season in summer; B one long rainy season with dry winter, C has one long rainy season with rainfall peaks in spring and summer to autumn, separated by a season with less rainfall, D is a dry region with rainfall from autumn to spring and small rainfall peak in summer, E has Minor rains in spring, major rains in summer, and F has two short rainy seasons, main rains in spring, minor rains in autumn. Source: Food and Agricultural Organization (1984).

Figure 2—Model structure. Each run of the model simulates a 30 year period over which insurance is provided, and calculates the minimum amount of starting capital needed to be raised in order to keep the insurance scheme solvent. The model does this assuming (a) separate, and (b) pooled capital accounts across locations. To obtain a distribution of starting capital requirements, we performed 10,000 runs of the model.

Figure 3—Model verification. To verify that the model was simulating a plausible insurance market, we calculate payouts during the period for which we had data. The drought of 1984 is clearly evident in the form of high payouts, as are years such as 1989 of plentiful rainfall and low payouts. 2002, the last year in the time series, does not show large payouts, which is consistent with the greatest rainfall shortages in that year of famine occurring in pastoralist areas, not covered by the model.

Figure 4—Results of Monte Carlo simulations. The curves show the cumulative proportion of insurance schemes' requirements for initial capital. The black curve assumes one insurance scheme covering all 15 sites, showing that initial capital at approximately 45% of the total insured value would be sufficient to avoid insolvency of the insurance company under 95% of the model runs. The dark grey curve shows all possible combinations of 3 locations pooled together, the while the lighter grey curve shows all possible combinations of 2 locations pooled together. The very light grey curve shows 15 separate insurance schemes, once for each site. About half of these sites could get by with about 90% or less of total insured value as their initial capital, while the most risky of them would require 350% of total insured value as initial capital.

Figure 5—Annual rainfall correlation coefficients between the 15 sites. The lightness of the lines shows the degree of correlation between sites. The black lines are the most negatively correlated,

while the lightest lines are the most positively correlated. There does not appear to be a clear spatial pattern.

Figure 6—Relationship between rainfall correlation and capital saving. Schemes that pool sites that are more negatively correlated tend to generate greater capital savings. The trend is highly significant (*student's t* = 5.86, *P* < 0.001), but captures only a quarter of the variance in capital savings.

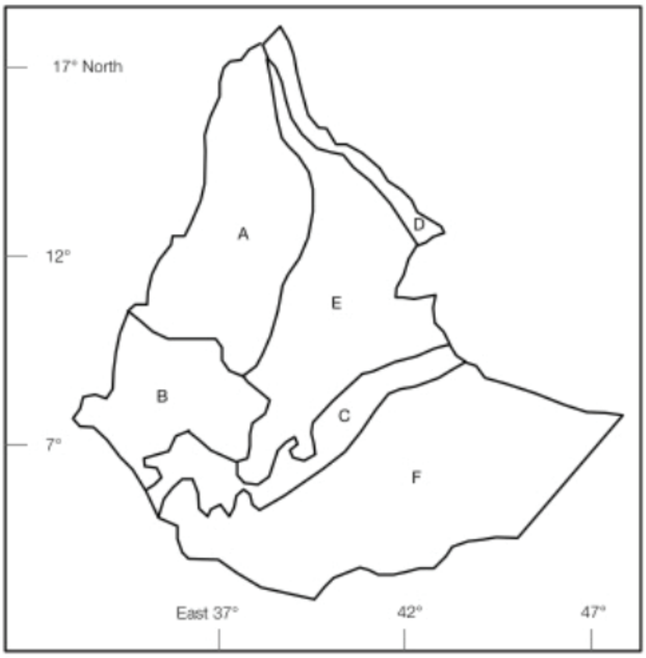

Figure 1