

Climate change and financial adaptation in Africa. Investigating the impact of climate change on the robustness of index-based microinsurance in Malawi

Stefan Hochrainer · Reinhard Mechler · Georg Pflug

Received: 7 May 2008 / Accepted: 22 September 2008 /
Published online: 4 December 2008
© Springer Science + Business Media B.V. 2008

Abstract This paper discusses the applicability of crop insurance for the case of Malawi and explores the potential impact of climate change on the viability of the Malawi weather insurance program making use of scenarios of climate change-induced variations in rainfall patterns. The analysis is important from a methodological and policy perspective. By combining catastrophe insurance modeling with climate modeling, the methodology demonstrates the feasibility, albeit with large uncertainties, of estimating the effects of climate variability and climate change on the near- and long-term future of microinsurance schemes serving the poor. By providing a model-based estimate of insurance back-up capital necessary to avoid ruin under climate variability and climate change, along with the associated uncertainties and data limitations, this methodology can quantitatively demonstrate the need for financial assistance to protect micro-insurance pools against climate-induced insolvency. This is of major concern to donors, NGOs and others supporting these innovative systems, those actually at-risk and insurers providing insurance. A quantitative estimate of the additional burden that climate change imposes on weather insurance for poor regions is of interest to organizations funding adaptation. Further, by linking catastrophe modeling to regionalized climate modeling, the analysis identifies key modeling inputs necessary as well as important constraints. We end with a discussion of the opportunities and limits to similar modeling and weather predictability for Sub-Saharan Africa beyond the case of Malawi.

Keywords Adaptation · Drought · Agricultural risks · Risk management · Microinsurance · Climate insurance · Catastrophe modeling

1 Introduction

Adaptation to climate change has emerged on the climate policy agenda alongside the reduction of atmospheric greenhouse gas concentrations as an essential part of the response

S. Hochrainer · R. Mechler (✉) · G. Pflug
IIASA, Laxenburg, Austria
e-mail: mechler@iiasa.ac.at

to climate change risks. The call for intensified support for adaptation in the developing world has been reinforced by the recent report from the International Panel on Climate Change (IPCC), which reports evidence of *current* climate change impacts on extreme weather including droughts, heavy precipitation, heat waves and the intensity of tropical cyclones (Solomon et al. 2007). Insurance-related instruments that spread and pool risks may be important candidates for supporting adaptation to climate-related disasters in developing countries (Linnerooth-Bayer et al. 2003). International financial institutions, as well as some bi-lateral donor organizations, are already providing assistance for catastrophe insurance schemes that serve low-income clients in Latin America, Asia and Africa, and the World Bank is exploring the idea of a global facility for hedging developing country risk (World Bank 2005). As one important instance, the *Bali Action Plan*, which should ultimately lead to a follow-up treaty to the Kyoto Protocol under the United Nations Framework Convention on Climate Change, calls for "... Enhanced action on adaptation, including, inter alia, consideration of risk management and risk reduction strategies, including risk sharing and transfer mechanisms such as insurance" (UNFCCC 2007). To date, however, there is little understanding or agreement within the climate community on the role that insurance and other forms of risk sharing can play in assisting developing countries adapt to climate change.

Both development organizations and agencies responsible for climate-change adaptation are thus closely observing recent experience with micro-insurance schemes to ascertain their potential for reducing vulnerability to climate-related weather variability and extremes. Of particular interest is the pilot weather insurance scheme in Malawi, a food-insecure, hazard-prone country with a large share of its- subsistence farming population living in poverty, which offers index-based drought insurance to smallholder groundnut farmers. Although there is mounting evidence that climate change is and will continue to affect adverse weather extremes throughout Southern Africa (Solomon et al. 2007), to date, neither the Malawi scheme nor (to our knowledge) other disaster insurance schemes operating in developing countries have taken account of information from climate-change models. This paper examines the case of microinsurance in Malawi and presents an approach for integrating modeling of climate variability and change with catastrophe modeling in order to assess the effects of climate change on the viability of the Malawi insurance scheme.

Quantitative risk assessment of effects due to climate changes are not only of interest to the Malawi program, but the development of methodologies to estimate the additional risks of climate change to insurance programs is of interest to development institutions, as well as organizations supporting adaptation to climate change. These communities could benefit from estimates of the burden that climate change will impose on the viability of the systems, as well as information on the additional capital needed to ensure their survival. For instance, if insurance programs are to qualify for funding from the Adaptation fund created at COP 13 in Bali, it is necessary to identify the extent to which climate change is adding to their costs or increasing the risks of their failure. This issue is not only of interest for disbursing climate adaptation funds, but generally for assessing the robustness of insurance and other mechanisms for managing climate risks in light of mounting evidence that climate change is and will continue to contribute to increasing losses from weather extremes.

Research in this field is only just emerging. Work on risk financing options for adaptation to climate variability and change is increasingly receiving attention (Müller 2002; Linnerooth-Bayer et al. 2005; Bouwer and Vellinga 2005; World Bank 2005; Bals et al. 2006; Linnerooth-Bayer and Mechler 2007). Also, assessments of climate change impacts and vulnerability have changed in focus from an initial analysis of the problem to

the assessment of potential impacts to a consideration of specific risk management methods (Carter et al. 2007). The implementation, analysis and donor support of risk-transfer programs in developing countries has become feasible largely as a result of advances in catastrophe modeling that make it possible to better estimate and price low-probability extreme event risks for which there are limited historical data. Catastrophe models typically generate probabilistic losses by simulating stochastic events based on the geophysical characteristics of the hazard and combining hazard data with analyses of exposure in terms of values at risk and vulnerability of assets. In addition, there has been important progress in the mathematics of extreme value theory, and in the convergence of the theories of finance and insurance rendering possible the pricing of more exotic risk-transfer instruments, such as weather derivatives and catastrophe bonds (Embrechts et al. 1997; Geman 1999). Furthermore, the modeling of the climate system has experienced substantial improvements. Global circulation models (GCMs) have been improved from accounting for land surface and cryosphere effects to capturing biosphere, carbon cycle and atmospheric chemistry as well. Also, regional climate models with a higher resolution (typically 50 km) have been developed in order to study local effects such as orographic ones. For example, the Hadley Centre has developed a PC version of such a model for any world region, the *Precis* model (Met Office 2007). Such model development has led to new types of vulnerability and impact studies and is effectively being followed here.

Yet, catastrophe insurance modeling and climate change modeling have rarely been brought together and often operate in isolation. As Mills (2005) points out, insurance modeling has essentially been backward-looking with a focus on historical trends in order to price and offer short-term contracts; on the other hand, modeling by the climate change community is looking into long future time horizons and has not been directly amenable to decision-support input for the insurance industry. Our paper should be understood as an attempt to link modeling in those two domains, advance the understanding of the potential and limits of such analyses, and outline crucial gaps to be filled by further research. The paper provides a quantitative estimate of the potential impact of climate change on the viability of the Malawi weather insurance program, and assesses the uncertainties of this estimate. Insurance modeling and climate change modeling are integrated, and by combining the two, the methodology demonstrates the feasibility of estimating the effects of climate change on the near- and long-term future of microinsurance schemes serving the poor. By providing a model-based estimate of the incremental role of climate change, along with the associated uncertainties, this methodology can quantitatively demonstrate the need for financial assistance to protect insurance pools against climate-change induced insolvency.

The paper is organized as follows: Section 2 describes the Malawi scheme and its insurance characteristics and conditions in the context of microinsurance. Section 3 outlines our methodology. Section 4 discusses data input, modeling details and the financial analysis conducted. Section 5 summarizes key findings and discusses the applicability of similar analysis beyond Malawi.

2 The Malawi insurance scheme: characteristics and conditions

2.1 The case for insurance in Malawi

Malawi is one of the more food-insecure countries in the Southern African region. In addition to droughts, an AIDS pandemic, declining soil fertility, shortages of land (most

farmers have small holdings from 0.5 ha to 3 ha) and inadequate agricultural policies contribute to the country's vulnerability. Life expectancy in Malawi is approximately 38 years, and about 6.3 million Malawians (50% of its 12 million population) live below the poverty line, the majority in rural areas with more than 90% relying on rain-fed subsistence farming to survive (Action Aid 2006; Osgood and Warren 2007). As reported by the UN Food and Agriculture Organization, 4% of Malawians were undernourished in 2003, down from 4.8% in 1992 (Skoet and Stamoulis 2006). Food insecurity is widespread, and evidence suggests that increased droughts and floods may be exacerbating poverty levels, leaving many rural farmers trapped in a cycle of poverty and vulnerability (Action Aid 2006).

In times of need, different resources may be tapped. Donor and government aid is a key resource, yet such assistance is volatile, and with the exception of highly publicized disasters (e.g., the 2004 Indian Ocean Tsunami), aid is usually only a small fraction of what is needed. Humanitarian assistance reported by the Organisation for Economic Cooperation and Development (OECD) Development Aid Committee in the 1990's was less than 10% of disaster losses in recipient countries (Mechler 2004). Post-disaster arrangements are not only often insufficient for meeting needs for relief and reconstruction, but they tend to be ad hoc and inefficient (Cardenas et al. 2007). In the absence of government assistance and international aid, poor victims have to rely on an array of (often innovative) pre- and post-disaster arrangements for financing their recovery. As shown on Table 1, insurance is only one of many different modalities for this purpose. The most usual financial course is to raise needed capital after a disaster strikes: Individuals take out emergency loans from family, micro-credit institutions or money lenders; sell or mortgage assets and land; or rely on public and international aid. Likewise, governments raise post-disaster capital by diverting funds from other budgeted programs, borrowing money domestically, or taking loans from international financial institutions.

While many locally based funding sources, for example, borrowing from neighbours or family, appear to work reasonably well for small localized events (Cohen and Sebstad 2003), they are problematic for catastrophes that affect large regions or many persons at the same time (so-called co-variant or systemic risks). To hedge against co-variant risks, households may purposely locate family members outside of harms way or diversify their livelihoods. They may also arrange contingent savings or food supplies, activities that spread risks temporally. Alternatively, households/businesses and farms can purchase

Table 1 Examples of pre- and post-disaster risk financing arrangements. Source: Linnerooth-Bayer and Mechler 2007

	Security for loss of assets (households/businesses)	Food security for crops/ livestock loss (farms)	Security for relief and reconstruction (governments)
Post-disaster (ex post)	emergency loans; money lenders; public assistance	sale of productive assets, food aid	diversions; loans from World Bank and other IFIs
Pre-disaster (ex ante)			
Non-market	kinship arrangements	voluntary mutual arrangements	international aid
Inter-temporal	micro-savings	food storage	catastrophe reserve funds, regional pools, contingent credit
Market-based risk transfer	property and life insurance	Crop and livestock insurance (also index based)	Insurance or catastrophe bonds (also index based)

property or crop insurance, which spreads risk both temporally and spatially. Insurance can be provided by micro-insurance programs, which are distinguished from other types of insurance by their provision of affordable cover to low-income clients. Like individuals, governments can also spread risks temporally and spatially by setting up reserve funds or regional pools and by purchasing insurance or hedging instruments (e.g., catastrophe bonds or contingent credit), respectively.

Many of these risk financing modalities are conventional; yet, some, most notably index insurance and catastrophe bonds, are rather novel and have been made possible by new developments in modeling risks and financial transactions. Whereas conventional insurance is written against actual losses, index-based (parametric) insurance is written against physical or economic triggers. Index-based insurance is against *events* that cause loss, not against the *loss* itself. For example, crop insurance may be based on measures of insufficient rainfall at key points in the growing season or a loss index determined by the correlation between historical weather events and crop yields in a region. The insurer will pay out if rainfall measured by a rain gauge falls below a specified level regardless of crop damage. The major advantage of index-based insurance is the substantial decrease in transaction costs, which, particularly for developing countries, have impeded the development of insurance mechanisms. The major disadvantage is *basis risk*, which is the lack of correlation of the trigger with the loss incurred. If the rainfall measured at the weather station is sufficient, but for isolated farmers insufficient, they will not receive compensation for crop losses.

2.2 The Malawi scheme

The Malawi weather insurance scheme is a variant of index-based microinsurance, as it couples microlending with mandatory crop insurance rather than directly providing microinsurance to farmers. Without financial protection, lending to farmers, particularly to rainfed farmers, has been generally considered very risky by banks because of the high systemic risk of loan default in the aftermath of droughts and other weather extremes. Consequently, the dominant government response to recurrent drought-induced food crises in Malawi has been to provide ad hoc disaster relief (Hess and Syroka 2005). In this section we present the characteristics of the Malawi insurance scheme in more detail and take a brief look at the performance of the insurance contract based on past rainfall data in the area around Chitedze, one of the four locations, where the microinsurance scheme is operational (see Fig. 1).

The packaged loan and index-based microinsurance product was first offered in 2005 by the Opportunity International Bank of Malawi (OIBM) and the Malawi Rural Finance Corporation (MRFC) to groups of groundnut farmers organized by the National Smallholder Farmers' Association of Malawi (NASFAM). Technical assistance was provided by the World Bank and Swiss development assistance via the Swiss Secretariat for Economic Affairs (SECO).¹ The farmer enters into a loan agreement with a higher interest rate that includes a weather insurance premium, which the bank pays to the insurer, the Insurance Association of Malawi (IAM). In the event of a severe drought (as measured by the rainfall index), the borrower pays a fraction of the loan due, while the rest is paid by the insurer directly to the bank. Thus, the farmer is less likely to default, which has a stabilizing effect on the bank's portfolio and risk profile. Without this assurance, banks rarely loan to high-risk, low-income farmers. The advantage for farmers is that they obtain

¹ Based on personal communication with H. Ibarra and World Bank (2005).

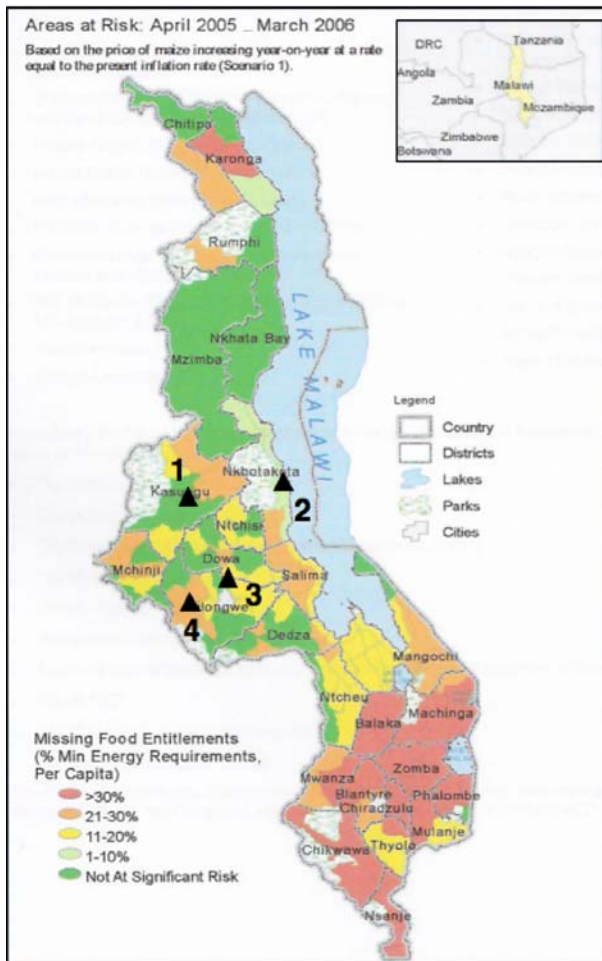


Fig. 1 The microinsurance pilot regions in Malawi: (1) Kasungu, (2) Nkhotakota, (3) Lilongwe and (4) Chitedze on a map of food entitlement risks (MVAC 2005)

the credit they need for investing in seeds and other inputs necessary for higher-yield crops. It is envisaged that by granting farmers access to higher-performing crops, they will adopt higher yield—higher risk activities. The World Bank together with Opportunity International was the catalyst in developing such a weather insurance product to secure credit for groundnut farmers (see Table 2).

In November 2005 the first policies were sold and about 900 smallholders in Malawi bought weather insurance that allowed them to access an input loan package to purchase better groundnut seed. Insurance premiums were substantial, amounting to a mark-up in interest of 6–10% of the insured loan value, depending on the location. This is in addition to the 33% annual interest rate charged on the loan (Malawian inflation rate is about 15% and low-risk, treasury bonds offer 26% interest). In the 2006 season, the renewal rate of policies was about 100%, and additionally a number of other farmers joined the scheme bringing up the total number of policies sold to 3,000 (which

Table 2 Characteristics of Malawi schemes for insuring credit and savings. Source: Mechler and Bayer 2006; Syroka 2007

Provider (year of inception)	NASFAM with banks OIBM and MRFC, and insurer IAM (2005)
Delivery model	Partner-agent, group-based: Weather Crop Insurance priced into loan offered to farmers, bank thus is insured and receives claim in case of event
Premium	6–10% of insured crop value as mark-up interest on loan
Cover	Outstanding loan with bank paid by insurer
Clients	2005: 900 farmers with four weather stations (sum insured \$35,000), 2006: 2,500 policies with five weather stations (sum insured \$110,000)
Reinsurance	No
Assistance	World Bank and SECO with technical assistance and catalyzing function
Major event experienced?	No, but some smaller payouts in 2005/06 season
Outlook	May finally lead to higher yield—higher risk activities as first evidenced in the bumper crop of 2008

is a still a rather small participation number for any insurance scheme). The scheme has not been put to test in a major drought event, but some localized payouts were triggered in the 2005/06 season.

3 Methodology

3.1 Overview

Climate change impacts on the Malawian microinsurance scheme can be assessed from two perspectives: From the view of the insurers (or *supply-side* perspective) it is important to analyze the financial robustness and risk of insolvency of the insurance scheme. From the view of the clients (the *demand-side*), it is important to consider financial robustness as it affects their livelihoods and the extent to which insurance reduces their financial vulnerability. Although the demand-side is clearly key to gauging the developmental and adaptation related benefits of insurance, our analysis takes an insurance-provider perspective for two reasons: First, if the system cannot withstand shocks from increasing weather variability, it will not only default on claims, but generally discredit insurance as an adaptive risk management option. Second, because commercial reinsurance will greatly raise premiums to clients who can ill afford any additional costs, the international development community is considering options for providing backup and pooling the risks of small-scale microinsurers offering catastrophe cover (Linnerooth-Bayer and Mechler 2007).

We make use of catastrophe modeling (*dynamic financial analysis*) to assess the financial robustness of the Malawi insurance scheme under dynamic weather and climate conditions as potentially altered by climate change. Dynamic financial analysis makes use of stochastic simulations of key insurance variables, such as surplus, loss ratios and solvency (or the risk of insolvency) based on inputs on insurance conditions and premium income (for example, see Lowe and Stanard 1997 or Ho 2005). In this case, claim payments are contingent on current and predicted rainfall data. The research capitalizes upon climatological and meteorological data computed within the World Bank sponsored project “Institutions for Climate Change Adaptation” by Mark Tadross et al. (2005). The analysis is based on observed changes in rainfall characteristics and derived downscaled climate change scenarios from both Regional Climate Models (RCMs), as well as

statistical downscaling for one site (Chitedze) in Malawi. Information on actuarial calculations was obtained from Dan Osgood of IRI, Columbia University, who conducted the original calculations that informed the Malawi scheme. The modeling approach is schematically represented in Fig. 2.

The input variables for modeling intensity and frequency of rainfall include the current rainfall patterns in Chitedze. To assess climate change impacts, we used the scenario based future rainfall patterns relying on the analysis of Tadross et al. (2005) and compared those to the current scenario. Furthermore, we implemented insurance conditions, such as contract and trigger events as currently employed in Malawi, in combination with the simulated rainfall amount to determine the claim payments for each year. Uncertainty issues are handled by means of sensitivity analysis and confidence intervals.

3.2 Insurance pricing and preliminary analysis based on historical data

The 2005-6 Malawi pilot project offered a bundled loan and insurance product in four pilot areas in central Malawi, where rainfall patterns compared to other areas in Malawi are relatively favourable for agriculture. The following analysis considers only the insurance (and not the full loan and insurance package) and assumes uniform conditions in these four areas based on information in only one (Chitedze). The premium pricing for this site follows Osgood (2006, Personal Communication) and, in keeping with standard practice, is based on the annualized payout (expected payout) under a contract and a risk premium accounting for the volatility of weather and disaster events, as well as transaction costs (for personnel costs for risk assessment and contract delivery) and a profit margin (Eeckhoudt and Gollier 1995)

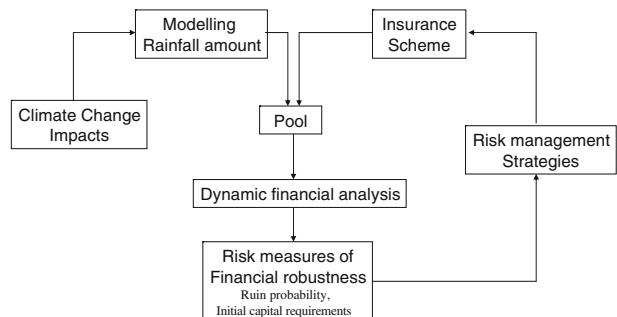
$$\text{Insurance premium} = \text{expected payout} + \text{risk premium} \\ (\text{loading factor} + \text{transaction cost} + \text{profit margin})$$

Distinct from “regular,” rather normally distributed insurance, such as car and health risks, the loading factor in the risk premium is a key determinant for natural disaster insurance premiums in order to hedge against potentially high, yet infrequent losses. Based on observations, in the case of Malawi, the pricing was operationalized as follows.

$$\text{Insurance premium} = \text{expected payout} + 6.5\% \\ (\text{value of losses at } 98^{\text{th}} \text{ percentile} - \text{expected payout})$$

The value of payout at the 98th percentile is set as the highest losses in the past given specified triggering events.

Fig. 2 Modeling approach from the insurance perspective



The ground input price (seed price times seed amount) per acre amounts to 3,200 Malawian Kwachas, the typical groundnut value (as the product of typical yield and expected harvest revenue) was calculated at 31,500 Kwachas. Adding a premium of 8.4% and an insurance tax on the premium of 17.5% on the typical loan value of 4,667 Kwachas leads to a premium of 461 Kwachas (or 9.9% of the loan). Further, since the primary risk to groundnut in Malawi is drought during the critical growth periods, the contract specifies levels of rainfall during a critical growing phase to release (*trigger*) a claim payment. Generally, three stages of development for groundnut crop can be distinguished: initial, crop development, and flowering phases. The insurance scheme, triggers and claim payouts are based on the accumulated amount of rainfall for each of the three phases.² Each phase is further subdivided into *dekads* (10 day growing periods). The contract also contains a “no sowing condition,” which triggers a full loan payout if a minimum level of rainfall is not received in order for the farmer to successfully sow the plant during the contract’s initial stages. If rain is above a certain level (e.g. 60 mm during germination stage), then there is no payout. If rainfall is insufficient for the crop to survive (e.g. less than 30 mm during germination), then insurance pays back the entire loan. If rainfall lies in between, interpolation defines what portion of the loan is paid by the insurance company. Thus, this contract can be viewed as essentially two contracts, one for catastrophic events (first 2 phases) and one for more frequent less dramatic losses (third phase) (Fig. 3). Because excessive rainfall in one dekad does not contribute to the growth in other dekads the rainfall amount for each dekad is capped at 60 mm per period. Figure 4 shows the historical simulated payouts with the contract scheme in its present form.

3.3 Current and future rainfall scenarios

The modeling of accumulated rainfall amount is based on input data of the Chitedze station in Malawi as analyzed and modeled by Tadross et al. (2005). Information of the input data used to construct current and future scenarios is based on the regional climate projection models MM5 and Precis and summarized in Table 3.

The main difference of the two RCMs is that they simulate a hydrological cycle of different intensity. In Precis there is more rainfall with a lower than observed intensity, whereas in MM5 there is more rainfall with a higher than observed intensity (Tadross et al. 2005). Both regional climate models are forced by the A2 emissions scenario. The SRES A2 scenario is a standard scenario used in assessing future worlds with climate change and leads to rather high greenhouse gas emissions (Nakicenovic and Swart 2001). Because future projections were expressed in monthly rainfall amount, it was necessary to downscale the projections to dekads of rainfall amount. This was based on past historical data. Figure 5 shows the mean rainfall amounts per dekad calculated from the empirical data as well as based on the MM5 and Precis models for the whole season (season starts at the beginning of August).

The MM5 future projections show lower rainfall in the beginning of the season compared to the mean empirical estimates. For the Precis model higher rainfall appears to characterize the beginning of the season. On the other hand, a trend with lower rainfall at the end of the season seems to emerge for Precis compared to the empirical data. While changes in the rainfall patterns can be assessed by using the mean changes, to account also

² The following trigger events are set in the 2006 contracts: Upper reps. lower claim triggers (in mm) for each phase were for phase 1: 35 and 30, for phase 2: 35 and 30, and for phase 3 220 and 20.

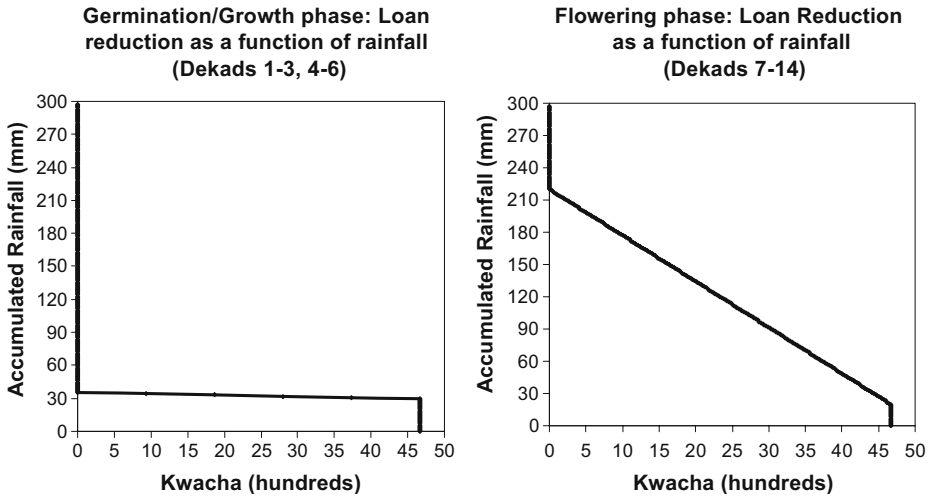


Fig. 3 Trigger events for phase one and two (germination and crop development phase) on the left, and phase three (flowering phase) on the right side. Source: Osgood 2006, Personal Communication

for changing variability in the future sensitivity analyses have to be performed. Two possible scenarios were assessed: (i) *Holding future variability constant*: In this approach, the consequences of a mean change in the future are examined while the coefficient of variation is held constant, i.e., the probability distribution of rainfall in the future has the same (normalized) dispersion as the corresponding distribution of the past calculated from the empirical data. (ii) *Changing future variability*: It is likely that future variability also increases; yet, the RCMs do not calculate variability. In order to account for such potential changes, the variance is changed by way of sensitivity analysis as discussed further below (Table 4).

The original climate projections relate to the 2070s (distant future). To also study the effects of climate change in the near future, i.e. the next 10 years, the following approach is adopted.

- The empirical mean distribution is set as the baseline case for the year 2005. Note that this distribution was calculated based on the time series 1961–2005. According to

Fig. 4 Simulated historical pay-outs based on rainfall data (in Malawian Kwacha, MWK)

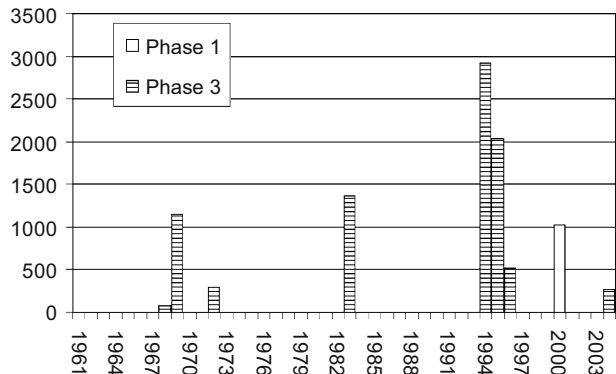


Table 3 Input data for the Malawi rainfall modeling

- Daily rainfall amount from 1961 until 2005 from Chitedze station.
- PRECIS rescaled projections (monthly rainfall) of the control and future period. Control is January 1960 to December 1979. Future period is January 2070 to December 2089.
- MM5 rescaled projections (monthly rainfall) of the control and future period. Control is from January 1975 to December 1984. Future period is January 2070 to December 2079.

Tadross et al. (2005) climate change effects were already observed in this time period. However, most of the variables were not significant, and those that were significant had very low correlations so it appears reasonable to consider the empirical mean distribution as the baseline case for 2005. The mean distributions from the two models, Precis and MM5, serve as the future distributions for 2080 and 2075, respectively.

- The difference between each dekade mean of the empirical and future distribution serve as the incremental steps from 2005 to 2080 and from 2005 to 2075, respectively. One simplistic assumption is that the steps are proportional to the future year minus the base year 2005. However, because the GCM is driven by the mean temperature rise over the time horizon, the incremental steps are assumed to be proportional to the temperature rise in the A2 scenario, which was also used for the Precis and MM5 projections. Therefore, for each year a new distribution is used to simulate the rainfall amount for each dekade. Again, first the mean value is changed over the years and the coefficient of variation is held constant. Afterwards, also the effects of an additional increase or decrease in the variance are analyzed. The output uncertainty is measured by confidence regions.

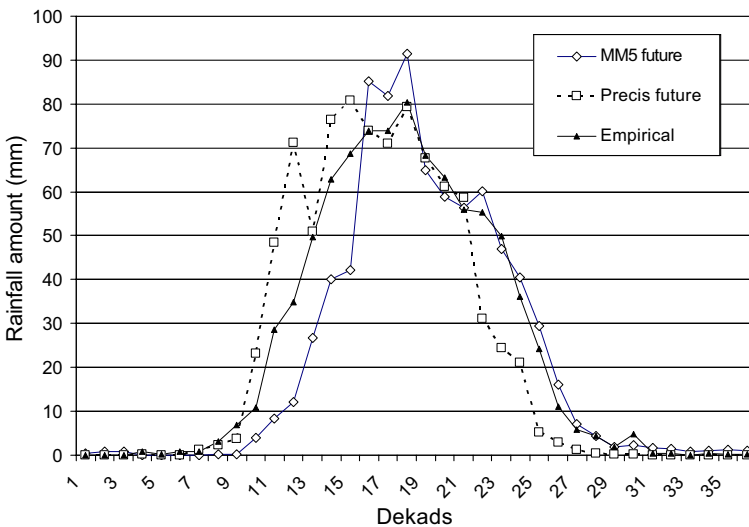


Fig. 5 Mean accumulated rainfall per dekade for the empirical data as well as the MM5 and Precis scenarios. Source: Calculations based on data from Tadross et al. 2005

Table 4 Accounting for current and future mean changes and variability in catastrophe modeling for the Malawi case

Analysis	Means captured	Variability captured
Climate variability	Modeled based on observations	Modeled based on observations
Climate change: distant future (2070s)	Modeled and derived from RCMs	Sensitivity analysis
Climate change: near future (2008–2017)	Modeled and derived from RCMs, then proportionally adjusted	Sensitivity analysis

For an examination of the contract based on the rainfall data of the Chitedze station, for each phase a gamma distribution³ was fitted. Given the upper trigger level for each phase, one can determine the probability that the amount of rainfall is below this value. This serves as a first risk estimate of the possibility of claim payments for each of the phases. For phase 1 the probability that the amount of rainfall is below 35 mm is 0.61%, for phase 2 the probability that rainfall is below 35 mm is 0.01%, for phase 3 the probability that rainfall is below 220 mm is 7.34%. In other words, a 164 year event (an event that happens on average every 164 years or with an annual probability of 0.61%) in phase 1, a 10,000 year event in phase 2, or a 14 year event in phase 3 would trigger the respective upper limits. The expected payout per acre for each phase (standard deviation in brackets) is for phase 1 22.1 (304) MWK, for phase 2 0.2 (27) MWK and for phase 3 66.1 (304) MWK. These results indicate that the contract is designed mainly for more frequent drought events with (usually) low claim payments. Catastrophic events can be expected to happen in phase 1 rather than in phase 2. Yet these observations may change in the context of climate change.

4 Dynamic financial analysis of the robustness of the scheme

We study the accumulation of the insurance capital for a time horizon of 10 years for the Precip and MM5 data. A random walk model was constructed assuming independence of the annual rainfall amount. For each year, 10,000 scenarios are simulated, resulting in a total number of 100,000 scenarios for each model. Each scenario comprises 36 dekads (i.e. 360 days). If capital accumulation falls below zero in a given year, insolvency occurs. Figure 6 shows estimated extreme value distributions of the insurance pool capital over time based on the empirical data and on the MM5 future projections. Climate change in these projections clearly has negative effects in the MM5 future model as compared to the baseline case. This can be seen by the fatter left-hand side tails of the distribution for the modeling based on the MM5 projections, indicating that the probability of insolvency is increased.

For a more detailed analysis we look at the probability of ruin and the initial capital required to prevent bankruptcy above some predefined threshold level. In the following, the consequences of mean and variability changes due to climate change are discussed for the near future (2008 until 2017) and a distant future period (around 2070), while noting associated uncertainties and possible implications.

³ Gamma distributions are standardly used for describing rainfall totals (see von Storch and Zwiers 1999)

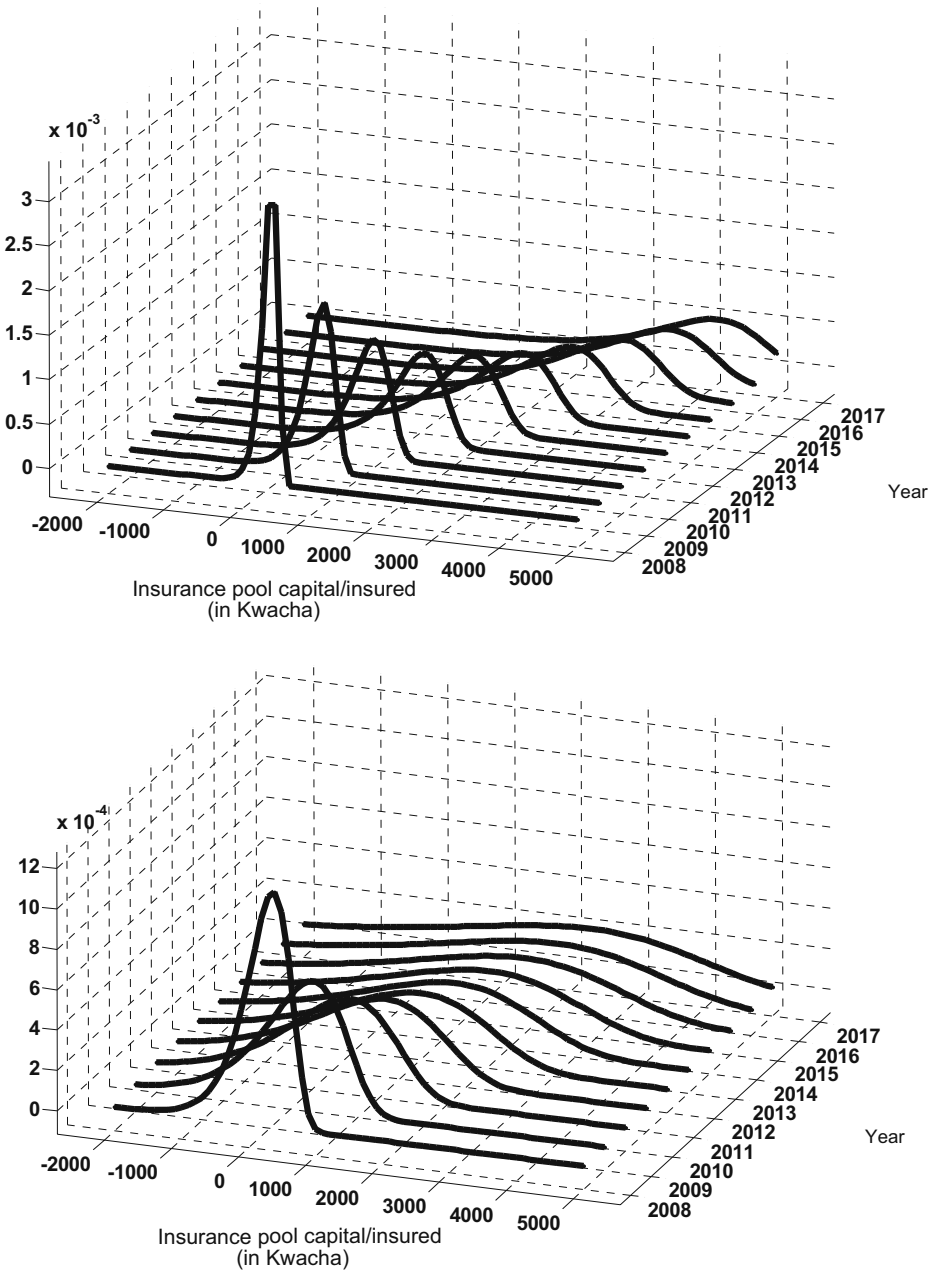


Fig. 6 Estimated (extreme value) distributions of insurance pool's capital for the baseline (*above*) and MM5 scenario (*below*) over a 10 year time horizon. Note: Ruin occurs if capital < 0

4.1 Consequences due to changes in rainfall patterns and variability

We begin by analyzing the consequences of climate change on the insurance pool based on two scenarios: (1) climate change will affect only the mean rainfall amount, and (2) the variability of the rainfall amount remains the same as in the past. A time horizon of 10 years is chosen. Table 5 shows the ruin probabilities (2008–17) for the baseline (empirical data), the MM5 and Precis models for (i) the future case (around 2070) and (ii) the near future case (2008–2017).

There is an increase of the ruin probabilities in the future case for both models. Especially, for the MM5 model the increase is dramatic. The probability of ruin is over 50% for a time period of 10 years. The increase is less dramatic for the near future; however, also here an increase of the ruin probabilities can be observed.

Because it is likely that in the future the variability of rainfall in Malawi will increase rather than decrease (see Tadross 2006), it is important to incorporate possible effects in the analysis. Ideally, one would estimate the variance of the future projections to get an estimate of the magnitude of change. However, due to data limitations with only 20 years of useable data available, such an exploration is not feasible. Accordingly, possible changes in future variance are implemented by way of sensitivity analysis. The future variance based on the empirical data is increased by a factor of 1.4 and decreased by a factor of 0.78 in the future, which corresponds roughly to a doubling and halving of the past variance (see Mearns et al. 1997).

As to be expected, the results are much more pronounced for all models compared to the baseline case. Additionally, compared to mean changes only, increased variability will worsen the negative effects on the insurance pool.

4.2 Risk management options for reducing the risk of insolvency

Basically, three options to reduce the risk of insolvency to the insurance scheme would be possible: (i) Adjusting premiums and payouts, (ii) increasing back-up capital, so as to decrease the probability of ruin to manageable levels, or (iii) changing the payout triggers and adjusting the contracts. Premium adjustment (increase for added variability) seems to be difficult as premiums are high already (6–10% of insured value), and 10% seems to be a prohibitive barrier for insurance (Mapfumo 2006, Personal Communication); changing the triggers is a straightforward option, yet difficult to implement for this analysis given the available data, and we discuss this in our final findings; for this exploratory analysis, we

Table 5 Probability of ruin for baseline, MM5 and Precis cases with mean changes only

Year	Baseline	MM5 future scenario	Precis future scenario	MM5 near future	Precis near future
2008	0.0738	0.2217	0.1081	0.0748	0.0741
2009	0.1139	0.3423	0.1643	0.1157	0.1147
2010	0.1359	0.4136	0.1953	0.1388	0.1368
2011	0.1482	0.4595	0.2138	0.1520	0.1493
2012	0.1551	0.4918	0.2255	0.1599	0.1566
2013	0.1594	0.5159	0.2333	0.1651	0.1611
2014	0.1621	0.5349	0.2385	0.1685	0.1639
2015	0.1639	0.5504	0.2422	0.1708	0.1659
2016	0.1652	0.5631	0.2449	0.1726	0.1672
2017	0.1660	0.5738	0.2469	0.1739	0.1681

look only at the latter option of changing the back-up capital. A simplifying assumption is that the pool does not hold backup capital in the initial year. Of course, the insurer will hold back-up capital either specifically for the Malawi pool, or will diversify its exposure by holding other “pools.” Yet, the back-up capital necessary for the case without climate change (“empirical”) serves as a baseline to which changes in necessary back-up capital are compared.

We start again with consideration of changing rainfall patterns only. Reversely calculating the insurance capital required for financial robustness in 95 (99)% of the cases over the 10-year time horizon leads to the following capital requirements per person with associated confidence intervals of the outcomes in brackets assuming a normal distribution (Table 6).

In all cases, additional backup capital would be needed to remain solvent at the 95 (99)% levels. Generally, Precis estimates were lower than those for MM5. The additional back-up capital required as a percentage of the premium for the next 10 years compared to the empirical case is significant, if small: 14% and 23% for the 5% resp. 1% ruin probabilities for MM5, and about 3% and 4% for the Precis model. For more significant climate change (here based on the A2 scenario to occur in the distant future around 2070), these additional requirements would rise very substantially for the MM5 to 621% and 871% and substantially for the Precis to 100% and 120% of the premium. Backup capital expressed in terms of premium ranges from 220% and 473% for the empirical, non-climate change case up to 840% and 1,289% for the MM5 case for 2070.

One additional important consideration here is the confidence of these estimates. As Monte Carlo simulations are used, there is uncertainty in these results. Confidence intervals of the outcomes of the simulations are shown. No overlap (with one exception for the Precis data at the 1% level) between the empirical and modeled results occurred indicating that the differences are (mostly) significant. The analyses of mean changes, therefore, show negative effects on the insurance pool to be expected in the near future and dramatic negative effects in the future.

Next we turn to the case of modeling an increase of the variability in the future. Again, the analysis is based on the MM5 and Precis models for the future (2070) and near future

Table 6 Insurance capital required for financial robustness in 95 (99)% of the cases over the 10 year time horizon (confidence interval in brackets) with mean changes

	Back-up capital to avoid insolvency with 95% probability (kwacha/person)	Back-up capital in % of premium (and additional back-up capital necessary compared to the baseline case in % of premium)	Back-up capital to avoid insolvency with 99% probability (kwacha/person)	Back-up capital in % of premium (and additional back-up capital necessary compared to the baseline case in % of premium)
Empirical	1013.3 [1006.4 1020.2]	220	2179.1 [2166.3 2191.9]	473
MM5 near future	1078.0 [1070.4 1085.6]	234 (14)	2283.2 [2267.7 2298.7]	495 (23)
Precis near future	1027.8 [1021.9 1033.7]	223 (3)	2196.2 [2181.2 2211.2]	476 (4)
MM5 future	3874.2 [3861.6 3886.8]	840 (621)	5943.5 [5918.9 5968.1]	1289 (871)
Precis future	1473.5 [1466.2 1480.8]	320 (100)	2730.6 [2715.9 2745.3]	592 (120)

(2008–2017). As already seen increased variability will worsen the negative effects on the insurance pool and hence will increase the capital requirements to remain solvent over time, as listed in Table 7. Including potential changes in variability of rainfall, leads to a significant revision of the additional back-up capital requirements for the next 10 years compared to the empirical case: 356% and 481% for the 5% respectively 1% ruin probabilities for MM5 (measured in percent of baseline premium), and about 335% and 455% in both cases for the Precis model. Figure 7 graphically displays those results including confidence intervals for mean changes only (left panel), as well as for mean and variability changes (right panel).

5 Conclusions and thinking beyond Malawi

The quantitative analysis of disaster risk management strategies is complex due to the nature of the phenomenon, e.i. its low probability, high impact characteristic. While the assessment of current extreme risks is already difficult and sophisticated methods have to be used to achieve reliable results, the tackling of future extreme risks is even more difficult. A key pre-requisite for analyses under climate variability and climate change are reliable data of the hazard for a sufficiently long time period. Malawi is a special case, in Sub-Saharan Africa with good time series of daily rainfall data for at least 21 weather stations. Hence, it was possible to build models and calibrate those based on observed data. Furthermore, accounting for climate change and downscaling to the regional level was possible due to available modeling and data. This allowed to couple climate change modeling with catastrophe modeling. Yet, key problems encountered were the focus of climate modeling on the distant future (2070s) and the lack of information on variability seriously limiting the modeling.

Given these caveats, according to our analysis climate-change induced stress will likely decrease the financial robustness of the Malawian insurance pool in the 10-year period between 2008–2017. With predicted stronger changes in rainfall patterns, climate change

Table 7 Insurance capital required for financial robustness in 95 (99)% of the cases over the 10 year time horizon with mean and variability changes

	Back-up capital to avoid insolvency with 95% probability (kwacha/person)	Back-up capital in % of premium (and additional back-up capital necessary compared to the baseline case in % of premium)	Back-up capital to avoid insolvency with 99% probability (kwacha/person)	Back-up capital in % of premium (and additional back-up capital necessary compared to the baseline case in % of premium)
Empirical	1013.3 [1006.4 1020.2]	220	2179.1 [2166.3 2191.9]	473
MM5 near future	2652.5 [2641.3 2663.7]	575 (356)	4398.5 [4375.7 4421.2]	954 (481)
Precis near future	2557.5 [2548.0 2567.0]	555 (335)	4276.7 [4258.4 4295.1]	928 (455)
MM5 future	7876 [7861 7891]	1708 (1489)	10533 [10503 10564]	2285 (1812)
Precis future	2973.3 [2963.1 2983.5]	645 (425)	4687.8 [4669.6 4706.0]	1017 (544)

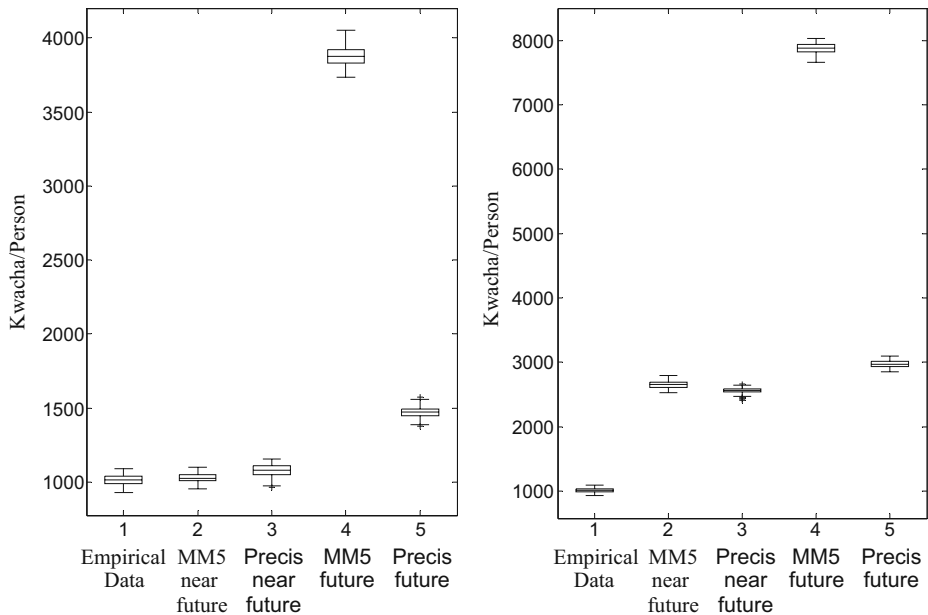


Fig. 7 Summary results of required insurance back-up capital needed if means are changed (*left plot*) and means and variability changed (*right plot*)

will likely have more dramatic negative effects in the distant 10-year period from 2070–2080. Assuming that premiums are not raised, additional back-up capital would be necessary to render the Malawi program robust at the 95% and 99% confidence levels. It should be kept in mind that these results are limited by the assumptions taken, as well as the input data and the climatological and insurance models employed. While data and climate-model uncertainty has not been accounted for in this analysis, uncertainty in terms of natural variability of the system has been expressed by sensitivity analysis, and output uncertainty derived from the modeling and simulation has been expressed by confidence intervals. Uncertainties in the estimates and derived projections are high, and further research is needed to refine the methodology. A first uncertainty relates to future states of the world and associated greenhouse gas emissions and temperature rise as given by the SRES scenarios. Data availability on rainfall greatly limits future projections, especially estimating future rainfall variability, which is a key factor influencing crop yields. This analysis has also not considered inter-annually correlated rainfall and drought patterns, e.g. due to the El Nino effects. Seasonal changes would negatively affect the insurance pool as set up currently and there are efforts underway to account for those in the contract design (see Suarez et al. 2008).

The implementation of crop and other weather insurance is strongly determined by data availability and predictability of weather patterns (which are to some extent interlinked) and the Malawi scheme scores well on both conditions. In terms of data availability, the Malawi meteorological data are considered good with over 30 years of data, few gaps and covering 21 primary synoptic weather stations. Of those weather stations, 4 were finally used for the insurance scheme, and three of the four stations used are associated with airports, where sufficient investment seemingly has been made to ensure data are reliable. In addition, there are over 200 rain gauges around the country and donor efforts underway to pilot the

installation of automatic weather stations which would help open up new agricultural areas to weather insurance (Syroka 2007).

Yet, in terms of climate and weather data and modeling, Malawi may not be the prototypical country in Sub-Saharan Africa, where research on observed and modeled weather and climate pattern has been limited, particularly as relates to extremes (Christensen et al. 2007). What concerns predictability, due to diverse conditions, such as geographic features (i.e. mountains), sea surface temperatures of the surrounding waters, the El Niño Southern Oscillation (ENSO) Phenomenon, as well as other factors such as capacity and governance of weather information, predictability of weather in the Sub-Saharan region differs considerably. The Lake Victoria area in Eastern Africa, to which Malawi belongs, and the Southern Africa region, are considered to be highly predictable, also owing to the existence of a larger number of weather stations and consistent time series collected (Hellmuth et al. 2007). Other, hazard-prone regions such as the region around Southern Ethiopia are considered only moderate predictable.

Some key assumptions used for the simulation are problematic and merit further discussion. Because of the complexity of the biological process of crop growth and changing rainfall patterns, trigger events are not changed over time, an assumption that may not be valid with climate change. In fact, a key benefit of insurance is that it is an option that is adaptive to changing environmental and economic conditions. Insurance contracts are essentially written on an annual basis, with premiums, deductibles and payouts reformulated as considered necessary from a supply and demand-side perspective. Thus, in effect, with improvements in foresight capacity (such as better modeled variability of weather under climate change), the Malawi scheme could be adapted over time to offer fair and catastrophe-robust premiums.

Notwithstanding the need for further refinements, the importance of this analysis goes beyond its implications for the Malawian insurance scheme and may offer important policy- and modeling relevant insights. The initiators of the Malawi program view it as a significant step forward in reducing farmer vulnerability and rural poverty in Malawi and potentially world wide (Hess and Syroka 2005). Whether the Malawi pilot program and others operating in Asia and Latin America fulfil the expectations of their initiators is a question of keen interest to the development and climate-change communities. If successful, the Malawi program can serve as one blueprint for development and donor organizations in their support of pre-disaster risk pooling schemes in poor and vulnerable regions in Africa and beyond. It can also be a blueprint for assisting adaptation to climate change. As Table 8 shows, there is clearly a need for innovative ex ante disaster risk management schemes for Southern Africa, including microinsurance schemes, for tackling drought, floods and other adverse weather contributing to food insecurity.

In terms of modeling, our methodology, combining catastrophe insurance modeling with modeling of climate variability and change, demonstrates the feasibility, albeit with large uncertainties, of estimating the effects of climate change on the near- and long-term future of microinsurance schemes serving the poor. By providing a model-based estimate of the incremental role of climate change, along with the associated uncertainties, this methodology can quantitatively demonstrate the need for financial assistance to protect insurance pools against climate-change induced insolvency. Because commercial reinsurance will greatly raise premiums to clients who can ill afford any additional costs, the climate community, alongside the international development community, is considering options, including regional and global risk pooling, for providing backup capital and pooling the risks of small-scale microinsurers offering catastrophe cover. The methodology demonstrated in this analysis, especially the quantitative estimate of the additional stress

Table 8 Reasons and persons affected by hunger in Southern Africa. Source: Hess and Syroka 2005

Country	1999	2000	2001	2002	2003
Angola	Civil strife	Civil strife	Civil strife	Civil strife	Civil strife
Lesotho	-	-	-	Adverse weather	Drought, frost
Madagascar	-	Cyclones, floods	-	Drought, economic problems	Drought, economic problems
Malawi	-	-	-	Adverse weather	-
Mozambique	Drought in parts	Floods, cyclones	Drought in parts	Drought in parts	Adverse weather
Swaziland	-	-	-	Drought	Drought
Zambia	-	-	Adverse weather	Adverse weather	-
Zimbabwe	-	-	-	Drought, economic disruption	Drought, economic disruption
Approximate number of affected persons (thousands)					
Southern Africa	1,825	2,350	4,425	16,700	9,500

climate change imposes on the Malawi system, can inform these options and thus bolster the case for supporting existing or emerging insurance arrangements for helping developing countries better cope financially with climate variability and change.

Acknowledgments Financial support under a grant from the Bank-Netherlands Partnership Program for the project “Institutions for Climate Change Adaptation” of the World Bank’s Development Research Group is gratefully acknowledged. We thank Alexander Lotsch for comments provided and project management, as well as Pablo Suarez and Joanne Bayer for comments received.

References

- Action Aid (2006) Climate change and smallholder farmers in Malawi: understanding poor people’s experiences in climate change adaptation. http://www.actionaid.org.uk/doc_lib/malawi_climate_change_report.pdf. Cited 1 Sep 2008
- Bals C, Warner K, Butzengeiger S (2006) Insuring the uninsurable: design options for a climate change funding mechanism. *Clim Pol* 6:637–647
- Bouwer LM, Vellinga P (2005) Some rationales for risk sharing and financing adaptation. *Water Sci. Technol.* 51:89–95
- Cardenas V, Hochrainer S, Mechler R, Pflug G, Linnerooth-Bayer J (2007) Sovereign financial disaster risk management: the case of Mexico. *Environ Hazards* 7:40–53
- Carter T, Jones R, Lu X, Bhadwal S, Conde C, Mearns L, O’Neill B, Rounsevell M, Zurek M (2007) New assessment methods and the characterisation of future conditions. In: Parry M, Canziani O, Palutikof J, van der Linden P, Hanson C (eds) *Climate change 2007: Impacts, adaptation and vulnerability. Contribution of working group II to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge, pp 133–171
- Christensen JH, Hewitson B, Busuioc A, Chen A, Gao X, Held I, Jones R, Kolli RK, Kwon WT, Laprise R, Magaña RL, Mearns L, Menéndez CG, Räisänen J, Rinke A, Sarr A, Whetton P (2007) Regional climate projections. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) *Climate change 2007: The physical science basis. contribution of working Group I to the fourth assessment report of the intergovernmental panel on climate change*. Cambridge University Press, Cambridge, pp 847–940
- Cohen M, Sebstad J (2003) Reducing vulnerability: The demand for microinsurance. *MicroSave-Africa*, Africa Eeckhoudt L, Gollier C (1995) Risk-evaluation, management and sharing. Harvester Wheatsheaf, New York

- Embrechts P, Klüppelberg C, Mikosch T (1997) Modeling extreme events. Springer, Berlin
- Geman H (eds.) (1999) Insurance and weather derivatives: from exotic options to exotic underlyings. Risk Books, London
- Hellmuth ME, Moorhead A, Thomson MC, Williams J (eds) (2007) Climate risk management in Africa: learning from practice. International Research Institute for Climate and Society (IRI), Columbia University, New York
- Hess U, Syroka H (2005) Weather-based insurance in Southern Africa. The case of Malawi. World Bank, Washington, D.C
- Ho TSY (2005) Asset/liability management and enterprise risk management of an insurer. JOIM 3:45–59
- Linnerooth-Bayer J, Mace MJ, Verheyen R (2003) Insurance-related actions and risk assessment in the context of the UNFCCC. Background paper for UNFCCC workshop on insurance-related actions and risk assessment in the framework of the UNFCCC, Bonn, 11–15 May 2003
- Linnerooth-Bayer J, Mechler R, Pflug G (2005) Refocusing disaster aid. Science 309:1044–1046
- Linnerooth-Bayer J, Mechler R (2007) Insurance against losses from natural disasters in developing countries. Background paper for United Nations World Economic and Social Survey 2008 (WESS).
- Lowe SP, Stanard JN (1997) An integrated dynamic financial analysis and decision support system for a property catastrophe reinsurer. ASTIN Bulletin 27:339–371
- Mearns LO, Rosenzweig C, Goldberg R (1997) Mean and variance change in climate scenarios: methods, agricultural applications, and measures of uncertainty. Clim Change 35:367–396
- Mechler R (2004) Natural disaster risk management and financing disaster losses in developing countries. Verlag für Versicherungswirtschaft, Karlsruhe
- Mechler R, Linnerooth-Bayer J, Peppiatt D (2006) Microinsurance for natural disasters in developing countries: benefits, limitations and viability. ProVention Consortium, Geneva
- Met Office (2007) Types of climate models: <http://www.metoffice.gov.uk/research/hadleycentre/models/modeltypes.html>. Cited 1 Sep 2008
- MVAC—Malawi vulnerability assessment committee (2005) Provisional results of the harvest outcome analysis. Lilongwe, Malawi
- Mills E (2005) Insurance in a climate of change. Science 308:1040–1044
- Müller B (2002) Equity in climate change: The great divide. Oxford institute for energy studies. Oxford, United Kingdom
- Nakicenovic N, Swart R (eds) (2001) Special report on emissions scenarios (SRES). Special report of the intergovernmental panel on climate change (IPCC). Cambridge University Press, Cambridge
- Osgood D, Warren D (2007) Drought insurance in Malawi. In: Hellmuth ME, Moorhead A, Thomson MC, Williams J (eds) Climate risk management in Africa: Learning from practice international research institute for climate and society (IRI). Columbia University, New York
- Skoet J, Stamoulis K (2006) The state of food insecurity in the world, 2006: Eradicating world hunger-taking stock 10 years after the world food summit. Food and Agriculture Organization of the United Nations, Rome
- Solomon S, Qin D, Manning M, Alley RB, Bertsen T, Bindoff NL, Chen Z, Chidthaisong A, Gregory JM, Hegerl GC, Heimann M, Hewitson B, Hoskins BJ, Joos F, Jouzel J, Kattsov V, Lohmann U, Matsuno T, Molina M, Nicholls N, Overpeck J, Raga G, Ramaswamy V, Ren J, Rusticucci M, Somerville R, Stocker TF, Whetton P, Wood RA, Wratt D (2007) Technical summary. In: Solomon S, Qin D, Manning M, Chen Z, Marquis M, Averyt KB, Tignor M, Miller HL (eds) Climate change 2007: The physical science basis. Contribution of working Group I to the fourth assessment report of the intergovernmental panel on climate change. Cambridge University Press, Cambridge, pp 19–91
- Suarez P, Osgood DE, Hansen J, Carriquiry M, Mishra A (2008) Integrating seasonal forecasts and insurance for adaptation among subsistence farmers: The case of Malawi. Policy research working paper 4651. World Bank, Washington D.C.
- Syroka J (2007) Insurance for farmers: Lessons learnt from India and Malawi. Presentation presented at the innovative finance meeting, New York, 18th October 2007. <http://www.un.org/esa/sustdev/dsissues/finance/egm2007/presentations/syroka.pdf>. Cited 1 Sep 2008
- Tadross MA (2006) Evidence of a changing climate in Malawi, Mozambique and Zambia: Analysis of daily rainfall data and regional models. Report for project “institutions for climate change adaptation”. Development Economics Research Group, Infrastructure and Environment Unit, World Bank, Washington D.C.
- Tadross MA, Jack C, Hewitson BC (2005) On RCM-based projections of change in southern African summer climate. Geophys Res Lett 32:L22713
- United Nations Framework Convention On Climate Change (UNFCCC) Secretariat (2007) Decision-/CP.13, Bali action plan, Bonn
- von Storch H, Zwiers FW (1999) Statistical analysis in climate research. Cambridge University Press, Cambridge
- World Bank (2005) Managing agricultural production risk. World Bank, Washington D.C.