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Investigating the Impact of Climate Change on the Robustness of Index-based Microinsurance in Malawi

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Abstract

This analysis 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 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 micro-insurance pools against climate-change induced insolvency. This is of major concern to donors, nongovernmental organizations, and others supporting these innovative systems; those actually at-risk; and insurers. A quantitative estimate of the additional burden that climate change imposes on weather insurance for poor regions is of interest to organizations funding adaptation.

This paper—a product of the Sustainable Rural and Urban Development Team, Development Research Group—is part of a larger effort in the department to study the implications of climate change. Policy Research Working Papers are also posted on the Web at http://econ.worldbank.org. The authors may be contacted at through alotsch@worldbank.org.

Investigating the Impact of Climate Change on the Robustness of Index-based Microinsurance in Malawi

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Keywords: Microinsurance, agricultural risks, dynamic financial analysis.

1 Introduction

Adaptation to climate change has emerged on the climate agenda alongside the reduction of atmospheric greenhouse gas concentrations as an essential part of the response 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 impacts in the form of long-term and widespread changes in wind patterns and aspects of 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, 2002). 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, 2005a). As one important item, 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, 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 integrates climate-change modeling with insurance modeling in order to assess the effects of climate change on the viability of the Malawi insurance scheme. The research addresses the following questions:

- Does climate change significantly increase the risk of insolvency of the Malawi microinsurance program (assuming farmers cannot pay higher premiums)?
- What additional capital input would be necessary to reduce the risk of insolvency to an acceptable level?
- What are the key uncertainties and how can they be expressed given the current state of climate and meteorological modeling and impacts assessment?

These questions are not only of interest to the Malawi program, but the development of methodologies to quantitatively 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. Both 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 Global Environment Facility (GEF), 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., 2003; Bouwer and Vellinga, 2005; World Bank, 2005a; Bals et al., 2006; Linnerooth-Bayer and Mechler, 2006). 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 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 the 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 modelling of the climate system has experienced substantial improvements. Global circulation models (GCM) have been improved from only 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 from mountains on climate. 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, insurance modeling (also called *dynamic financial analysis*[1]) and climate change modelling have rarely been brought together and operate in isolation. As Mills (2005) points out, insurance modelling has essentially been backward-looking with a focus on historical trends in order to price and offer short-term contracts; on the other hand, modelling by the climate change community is looking into longer time horizons in the

[1] More detail on dynamic financial analysis can be found in section 3.

future and has not been directly amenable to decision-support input for the insurance industry. Our paper should be understood as an attempt to link modelling in those two domains, advance the understanding of the potential of such analyses and outline crucial gaps to be filled by further research.

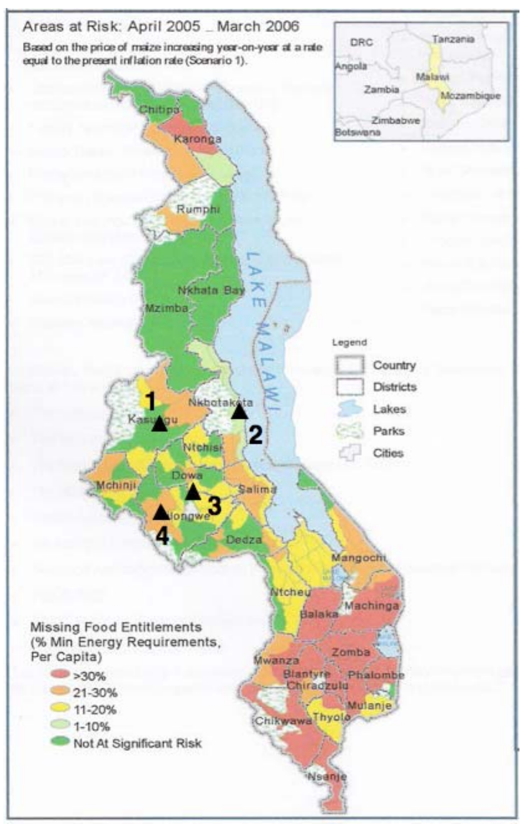
This paper provides a quantitative estimate of the potential impact of climate change on the viability of the Malawi weather insurance program, and assesses the uncertainties of this estimate. Insurance modeling and climate change modeling are integrated, and by combining the two, the methodology demonstrates 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 the methodology used. Section 4 discusses data input, modeling details and the financial analysis conducted. Section 5 focuses on results, followed by conclusions.

2 The Malawi insurance scheme: Characteristics and conditions

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 figure 1).

Fig. 1: The microinsurance pilot regions in Malawi: (1) Kasungu, (2), Nkhotakota, (3) Lilongwe and (4) Chitedze, depicted on a map of missing food entitlements in Malawi (MVAC, 2006).



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 so 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).

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). 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 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, but there is no evidence yet. The World Bank together with Opportunity International was the catalyst in developing such a weather insurance product to secure credit for groundnut farmers (Table 1).

Table 1: Characteristics of Malawi schemes for insuring credit and savings as of June 2007

Provider (country, year of inception of disaster insurance)	NASFAM with banks OIBM and MRFC, and insurer IAM (Malawi, 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 assets as mark-up interest on loan
Cover	Outstanding loan with bank paid by insurer
Clients	Ca. 900 (2005), 3000 (2006)
Reinsurance	No
Assistance	World Bank and SECO with technical assistance and catalyzing function
Major event experienced?	No, but some payouts in 2005/06 season
Outlook	Should lead to higher yield–higher risk activities but no evidence yet.

Source: Mechler and Linnerooth-Bayer, 2006

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 is still a small 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 (or the *demand-side* perspective), it is important to consider financial robustness as it affects their livelihoods and the extent to which insurance reduces their financial vulnerability. Because of the fragility of nascent insurance systems in developing countries, such as the pilot program in Malawi, this analysis takes a supply-side perspective. If the systems cannot withstand shocks from increasing weather variability, they will not only default on claims, but generally discredit insurance as an adaptive risk management option. 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 (Gurenko, 2006; Linnerooth-Bayer and Mechler, 2006). A supply side analysis can inform these options.

This paper makes use of *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 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 (Tadross et al., 2007). Information on actuarial calculations was obtained from D. Osgood (International Research Institute, Columbia University), who conducted the original calculations that informed the Malawi scheme. The modeling approach is schematically represented in Figure 2.

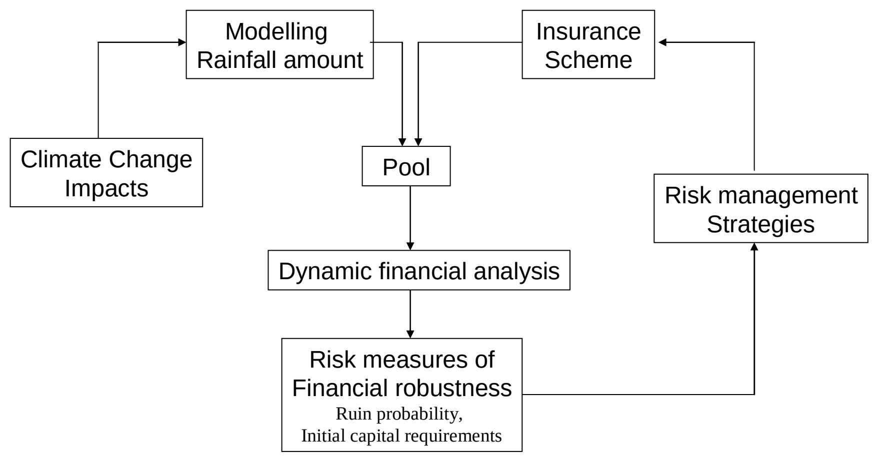


Fig. 2: Modeling approach from the insurance perspective.

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. A dynamic financial analysis for a 10-year time period is performed to analyze the financial robustness of the contract under the different climate change settings. Output variables include (i) the probability of ruin of the insurance pool as a measure of its robustness and, (ii) initial capital necessary to reduce the probability of ruin to 5% resp. 1% over 10 years.

By considering a 10-year time horizon, this analysis assesses the financial robustness (risk of insolvency) of the Malawi scheme by estimating the scheme's capital accumulation and depletion accounting for stochastic shocks under dynamic climatic conditions. The assumptions of the analysis are detailed below:

- All four regions in the Malawi pilot study are assumed to be identical to the Chitedze region for which more complete data exists;
- Insurance premiums and triggers are held constant;
- Insurance is stand-alone, i.e., the bundled credit-insurance structure and links between these financial instruments are not accounted for in this analysis;
- There is no accumulated back-up capital at the outset of the 10-year period;
- There is no opportunity for the insurer to diversify, and no reinsurance is purchased.

An important consideration is uncertainty, which is pervasive throughout the analysis. While input uncertainty, such as associated with rainfall projections, should ideally be incorporated in the analysis, because of the lack of information and data on the variability of rainfall, it is not dealt with quantitatively. Uncertainty in terms of natural variability of the system is expressed with sensitivity analysis. Output uncertainty, e.g. uncertainty that derives from the modeling and simulation, is expressed using 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 favorable 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) and, in keeping with standard practice, is based on the expected payout (expected value). This can be expressed as follows:

Premium = expected payout + 6.5% (Value of payout at 98th percentile – expected payout)

The value of payout at the 98th percentile is set as the highest losses in the past given specified triggering events. Furthermore, table 2 shows important input parameters and calculated variables (in bold) used for pricing the insurance scheme.

Table 2: Important parameter settings and computed values (in bold) for the groundnut insurance contract in Chitedze.

Variable	Value
Seed price (MWK/kg)	100
Seed amount (kg per acre)	32
Ground input price (MKW per acre)	**3200**
Typical yield (kg per acre)	420
Harvest price (MWK/kg)	75
Typical groundnut value (MKW per acre)	**31500**
Loan size (MKW per acre)	4667
Groundnut only insurance premium (%value)	8.4
Insurance tax (%)	17.5
Groundnut only insurance rate with tax (%)	**9.9**
Premium with tax (MKW per acre)	**461**

Note: MKW: Malawi Kwacha. Source: Osgood (2006).

The ground input price (seed price times seed amount) per acre amounts to 3200 Kwachas, the typical groundnut value (as the product of typical yield and expected harvest price) 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 4667 Kwachas leads to a premium of 461 Kwachas (or 9.9% of the loan size).

Since the primary risk to groundnut in Malawi is drought during the critical growth periods, the contract specifies levels of rainfall that trigger a claim payment. There are four stages of development for the groundnut crop: initial, crop development, mid-season and late season. Because the mid-season and late season can be grouped as the flowering phase, the insurance contract in 2006 for Chitedze considered only three phases. The insurance scheme, trigger and claim payouts are based on the accumulated amount of rainfall for each of the three phases. The following trigger events are set in the 2006 contracts (Table 3 and Figure 3):

Table 3: Upper and lower claim triggers for each phase (in mm)

	Upper trigger (mm)	Lower trigger (mm)
Phase 1	35	30
Phase 2	35	30
Phase 3	220	20

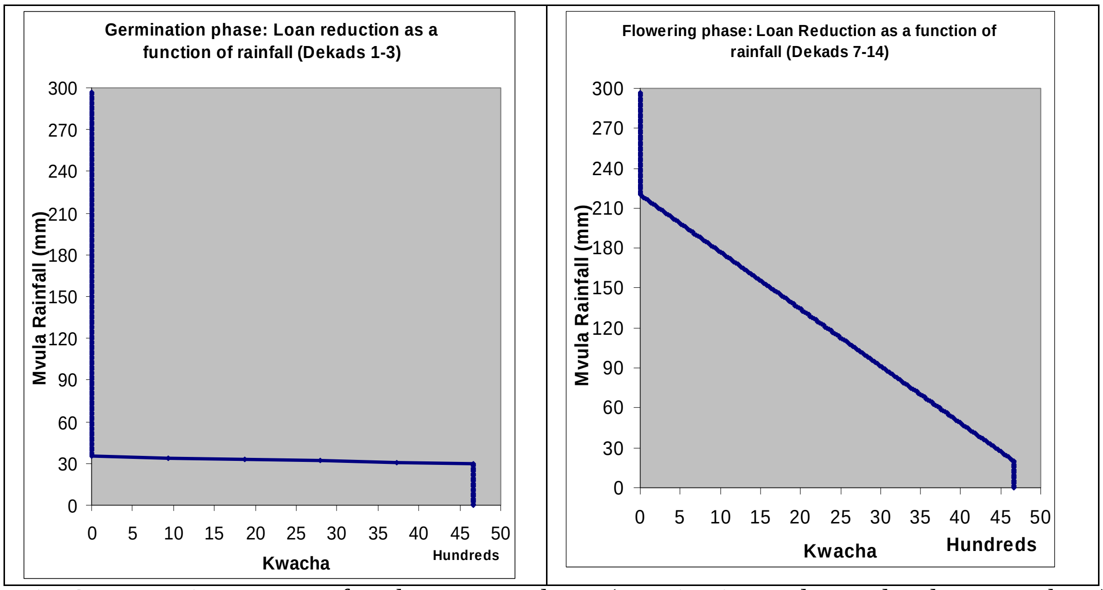


Fig. 3: Trigger events for phase one and two (germination and crop development phase) on the left, and phase three (flowering phase) on the right side. Source: Osgood, 2006.

Each phase is further subdivided into *dekads* of 10 days. 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. 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. Thus, this contract can be viewed as essentially two contracts, one for catastrophic events (first 2 phases) and one for more frequently less dramatic losses (third phase). Figure 4 illustrates the difference of the payout for (i) capped and (ii) non-capped rainfall data between 1961 and 2005.

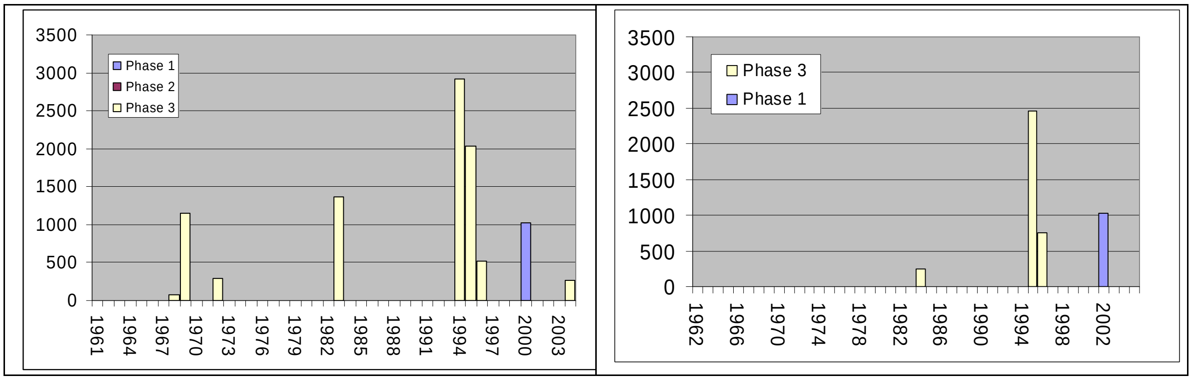


Fig. 4: Historical simulated payouts of drought insurance contracts based on (left) capped and (right) non-capped rainfall data from 1961 to 2005

With the capped data, the third phase is more frequently triggered with higher compensation than is the case for the non-capped data. Thus, capping has important implications both for the insured as well as the insurer. The contract in its present form provides insurance protection against frequent rather than catastrophic losses. However, this may change in the context of climate change.

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 (see Table 4).

Table 4: Input data for the rainfall modeling.

• Daily Rainfall amount from 1961 till 2005 from Chitedze station.
• PRECIS rescaled projections (monthly rainfall) of the control and future period. Control is January1960 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 December1984. Future period is January 2070 to December 2079.

The PSU/NCAR mesoscale model (known as MM5) developed by Pennsylvania State University and the National Center for Atmospheric Research is a limited-area, non-hydrostatic, terrain-following sigma-coordinate model designed to simulate or predict mesoscale atmospheric circulation.[2] Precis (Providing REgional Climates for Impacts Studies) is based on the Hadley Centre's regional climate modelling system.[3] Both regional climate models (RCM) are forced within the A2 emissions scenario global circulation model. 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). The main difference of the two RCM is that they

[2] See http://box.mmm.ucar.edu/mm5/
[3] See http://precis.metoffice.com/

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).

Because future projections were expressed in monthly rainfall amount, it was necessary to downscale the projections to dekads of rainfall amount. Downscaling was based on the empirical rainfall distribution of the Chitedze station. In detail, based on the historical rainfall amount for each dekad between 1961 and 2005, the mean rainfall amount for each dekad was calculated and transformed into a percentage of monthly rainfall amount. This percentage was used to distribute the monthly rainfall amount of the future projections into rainfall amount in dekads. Hence it is assumed that future rainfall patterns on average are the same as in the past. While this assumption is questionable, other approaches are not reliable due to lack of data. Furthermore, because the insurance trigger events are constructed for at least 3 dekads for each phase, changing distribution patterns within dekads are of minor interest from an insurance perspective. In this context the variance is of more importance. Figure 5 shows the mean distribution 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).

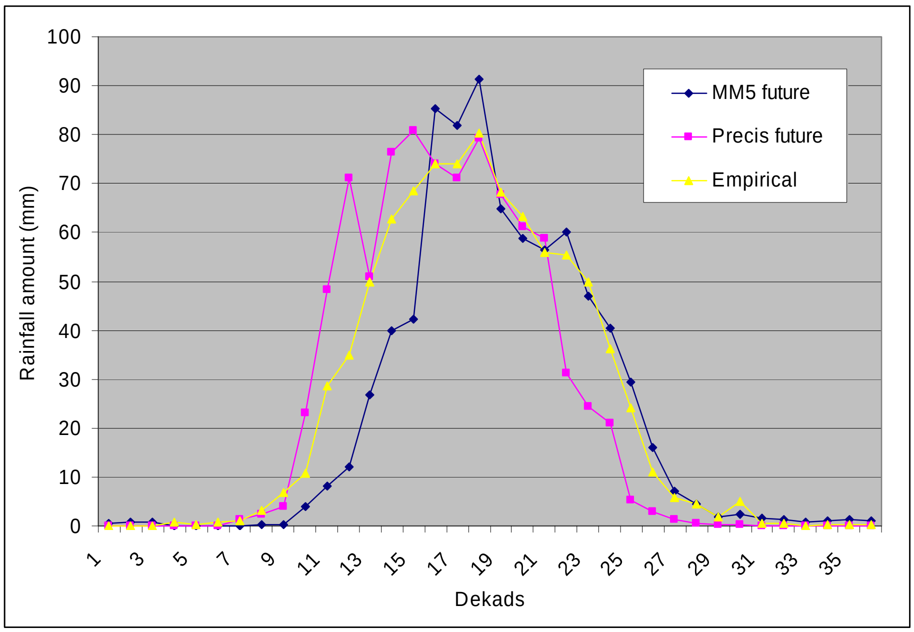


Fig. 5: Mean accumulated rainfall per dekad for the empirical data as well as the MM5 and PRECIS Scenarios
Source: Based on data from Tadross et al. 2005.

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. Usually, one would use the future projections to estimate the future parameters for each dekad and model. However, due to data limitations, e.g. the projections are only point estimates, especially for estimating the standard deviation around the dekads, two different approaches are taken for this analysis, each influencing uncertainty and variability of the results. The two approaches can be described as follows:

1. *Holding future variability constant:* In this approach, the consequences of a mean change in the future are examined while the variance is held constant, i.e., the probability distribution of rainfall in the future has the same variance as the corresponding distribution of the past as calculated from the empirical data.

2. *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.

The original projections lie in the distant future. To 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. Observe that this distribution was calculated based on the time series 1961-2005. According to 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 that the empirical mean distribution is considered 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 dekad 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 from the HadAM3P for 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 dekad. Again, first the mean value is changed over the years and the variance is held constant, so that the 'a' parameter can be estimated. Afterwards, also the effects of an additional increase or decrease in the variance are analyzed. The output uncertainty is measured by confidence regions.

For a preliminary examination of the contract based on the rainfall data of the Chitedze station, for each phase a gamma distribution[4] is fitted. Figure 6 shows the distributions for each phase with the estimated parameter. Due to the longer time horizon of phase three (80 days compared to 30 days for phase 1 and 2), the distribution for phase 3 is skewed to the right, indicating that the rainfall amount is generally higher compared to the other phases. Furthermore, phase 2 seems to have a higher rainfall amount compared to phase 1. For example, with 90 percent probability, the rainfall amount in phase 1 is below 306 mm, whereas for phase 2, the rainfall amount is below 340 mm. Given the upper trigger for each phase, one can determine the probability that the amount of rainfall

[4] A gamma distribution was chosen because it is standardly used for describing rainfall totals.

is below this value. For phase 1 the probability that the amount of rainfall is below 35 mm is 0.53 percent, for phase 2 the probability that rainfall is below 35 mm is 0.045 percent, for phase 3[5] the probability that rainfall is below 220 is 7.59 percent. In other words, a 188 year event (an event that happens on average every 188 years) in phase 1, a 2200 year event in phase 2, or a 13 years event in phase 3 would trigger the respective upper trigger limits.

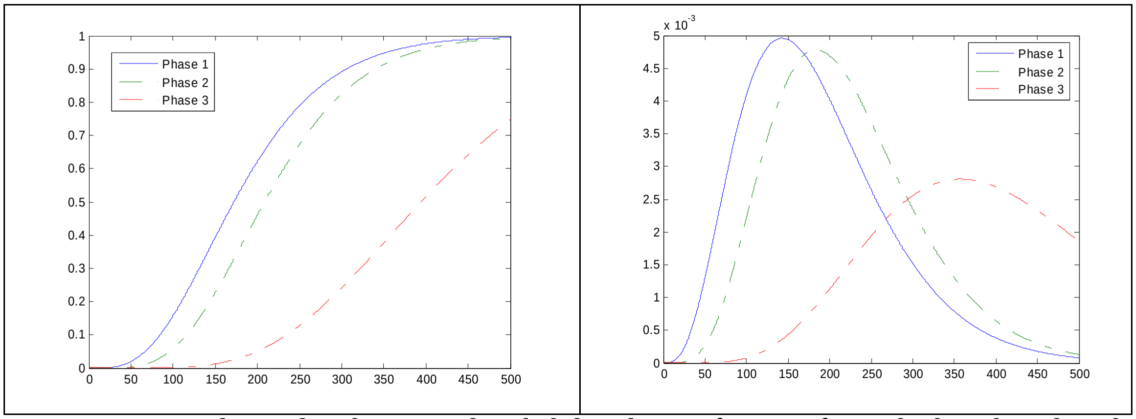


Fig. 6: Cumulative distribution and probability density function for each phase based on the rainfall data of the Chitedze station.

The expected payout per acre for each phase is also of interest. Instead of analytically solving the integral, Monte Carlo simulation (1 million samples) generates estimates of the expected losses and the standard deviation. The total loan is set to 4667.4 MWK. As a result the expected losses per acre in MWK are

- for phase 1 19.1 (288),
- for phase 2 1.4 (79) MKW, and
- for phase 3 68.5 (310) (standard deviation in brackets). [6]

4 Dynamic financial analysis: assessing the financial robustness of the microinsurance scheme

We now study the accumulation of the insurance capital for a time horizon of 10 years for the PRECIS 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 7 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 tails of the

[5] Here, the data are not capped.

[6] As discussed above, this contract can be seen as almost two contracts, one for catastrophic events (first 2 phases) and one for more frequently less dramatic losses (third phase).

distribution for the modeling based on the MM5 projections. This means that the probability of insolvency is higher.

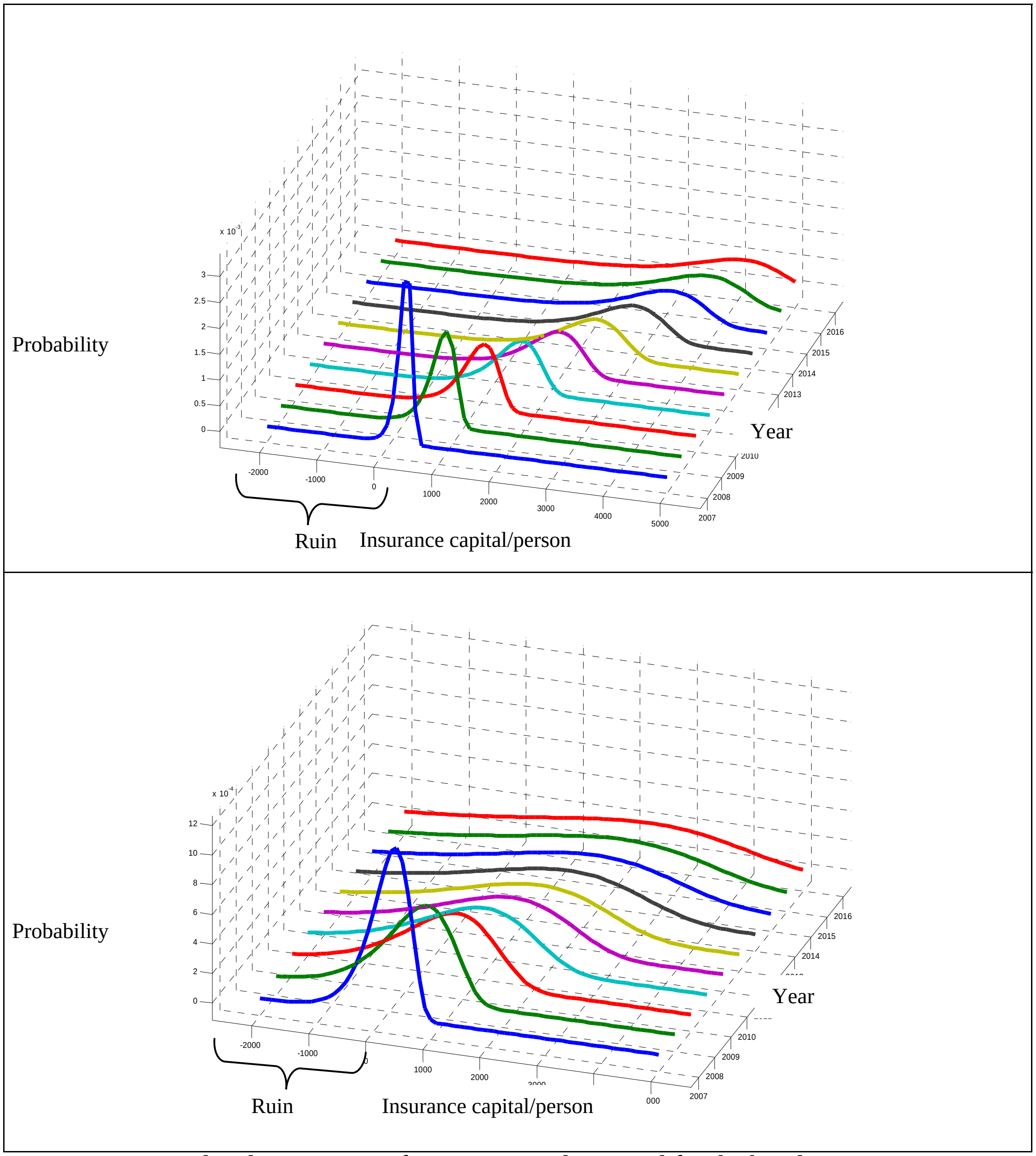


Fig. 7: Simulated trajectories of insurance pool's capital for the baseline (above) and MM5 scenario (below) over a 10 year time horizon

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, e.g. increasing the robustness of the pool. In the following, the consequences of mean and variability changes due to climate change for the near future, e.g. 2008 till 2017, and the future period around 2070, based on the information of the MM5 and Precis model, while associated uncertainties and possible implications are discussed.

5 Discussion of results

5.1 Mean changes due to climate change

We begin by analyzing the consequences of climate change on the insurance pool based on two conditions: (1) climate change will affect only the mean rainfall amount, and (2) the variance 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 model for (i) the future case (around 2070) and (ii) the near future case (2008-2017).

Table 5: Probability of ruin for baseline, MM5 and PRECIS cases

Year\Probability of Ruin (%)	Baseline	MM5 future scenario	Precis future scenario	MM5 near future	Precis near future
2008	0.0738	0.2217	0.1081	0.0748	0.0741
2008	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

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 percent 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.

Two options to reduce the risk of insolvency to the insurance scheme could be taken:

- Adjusting premiums and payouts,
- Increasing back-up capital, so as to decrease the probability of ruin to manageable levels.

Premium adjustment seems to be difficult as premiums are high already (6-10% of insured value) and thus we look only at the latter option. 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." 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.

Reversely calculating the insurance capital required for financial robustness in 95 (99) percent 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). Each simulation was performed 100 times and the mean and standard deviation were used to calculate the confidence levels.

Table 6: Insurance capital required for financial robustness in 95 (99) percent of the cases over the 10 year time horizon

	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)

In all cases, additional backup capital would be needed to remain solvent at the 95 (99) percent levels. Backup capital expressed in terms of premium ranges from 220% and 473% for the empirical, non-climate change case up to 840% and 1289% for the MM5 case for 2070. 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 817% and substantially for the Precis to 100% and 120% of the premium.

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 distant future. In the next subsection, an analysis of mean and variability changes is presented, whereby variability is added in the form of sensitivity analysis.

5.2 Mean and variability changes due to climate change

Because it is likely that in the future the variability of rainfall in Malawi will increase rather than decrease (see Tadross et al., 2007), 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 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, Rosenzweig and Goldberg, 1997). The probability density function of the gamma distribution has the following form

$$f(x \mid \alpha, \beta) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-\frac{x}{\beta}}, \quad x \geq 0$$

where is the shape parameter and is the scale parameter. The mean of the distribution is and the variance is . Hence, an increase of of 1.4 can be seen as doubling the rainfall variability compared to the baseline case, while a decrease of 0.78 can be interpreted as a one-half decrease of the variance compared to the baseline case. Thus, both parameters of the gamma distribution are now changing.

Table 7: Probability of ruin for baseline, MM5 and PRECIS with mean and variability changes

Year\ Probability of ruin (%)	Baseline	MM5 future scenario	Precis future scenario	MM5 near future	Precis near future
2008	0.0738	0.3789	0.2157	0.1509	0.1492
2008	0.1139	0.5607	0.3231	0.2362	0.2332
2010	0.1359	0.6621	0.3839	0.2877	0.2832
2011	0.1482	0.7254	0.4222	0.3206	0.3149
2012	0.1551	0.7694	0.4488	0.3434	0.3368
2013	0.1594	0.8019	0.4688	0.3598	0.3522
2014	0.1621	0.8270	0.4839	0.3725	0.3639
2015	0.1639	0.8469	0.4962	0.3826	0.3730
2016	0.1652	0.8633	0.5060	0.3908	0.3804
2017	0.1660	0.8769	0.5141	0.3977	0.3864

We discuss the results for the case of 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 (2008-2017). Table 7 shows the ruin probabilities under this new setting. As one would expect, the results are 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.

This can also be translated into initial capital requirements to remain solvent as listed in table 8.

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 8 graphically displays those results including confidence intervals.

Table 8: Insurance capital required for financial robustness in 95 (99) percent 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)

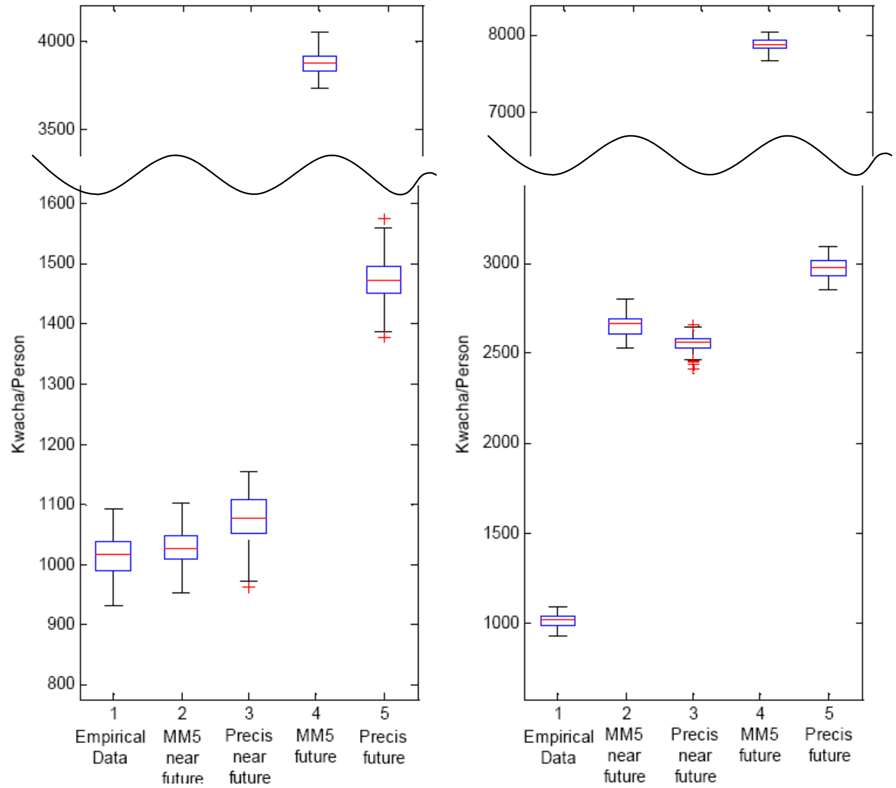


Fig. 8: Summary results of insurance capital if means are changed (left plot) and means and variance changed (right plot)

While it is not very plausible to assume decreasing variability, it is also possible to study possible effects on the insurance pool by means of sensitivity analysis in a similar fashion as for the rise in variability. Table 9 shows that, in general, decreasing vulnerability would increase the robustness of all future scenarios and insurance pools. Only the MM5 scenario would give negative results, mainly due to higher catastrophe losses in phase 1.

Table 9: Confidence intervals of capital requirements for an assumed decrease in variability

	Baseline	MM5 Future scenario	Precis future scenario	MM5 near future	Precis near future
5% level	1006.4 1020.2	7865 7887	424.5 434.9	359.7 371.0	339.2 351.9
1% level	2166.3 2191.9	10510 10556	1287.4 1309.0	1356.7 1377.2	1331.1 1355.2

6 Conclusions and outlook

According to this analysis, climate-change induced stress will likely decrease the financial robustness of the Malawian insurance pool in the 10-year period between 2008-2017 (“near future period of analysis”). With predicted stronger changes in rainfall patterns, climate change will likely have more dramatic negative effects in the 10-year period from 2070-2080 (“future period”). Assuming that premiums are not raised from current levels, 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 restrictive 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 with sensitivity analysis, and output uncertainty deriving from the modeling and simulation has been expressed with 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 represented by the SRES scenarios. A major limitation arises since probabilities are not associated with SRES-type scenarios. Data availability on rainfall greatly limits future projections, especially estimating future rainfall variability, which is a key factor influencing crop yields. Additional computer runs of the RCMs models would improve capacity for forecasting rainfall variability. 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.

Some key assumptions used for the simulation are problematic. 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. Nor does the analysis consider shifting to potentially more sustainable and drought-proof practices such as utilizing less-water-intensive crops or switch to livestock farming, as for example advocated in a study assessing robust drought management strategies under long-term change, including anthropogenic climate change, in the state of Andhra Pradesh, India (see World Bank, 2005b). Finally, this supply-side analysis did not consider basis risk to the farmers, which would be an important consideration for a demand-side focused analysis.

Notwithstanding the need for further refinements, the importance of this analysis goes beyond its implications for the Malawian insurance scheme. By combining catastrophe insurance modeling with climate modeling, the methodology 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 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 cope financially with climate variability and change.

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