Pitfalls and potential of institutional change: Rain-index insurance and the sustainability of rangeland management

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Abstract:

Rain-index insurance is strongly advocated in many parts of the developing world to help farmers to cope with climatic risk that prevails in (semi-)arid rangelands due to low and highly uncertain rainfall. We present a modeling analysis of how the availability of rain-index insurance affects the sustainability of rangeland management. We show that a rain-index insurance with frequent payoffs, i.e. a high strike level, leads to the choice of less sustainable grazing management than without insurance available. However, rain-index insurance with a low to medium strike level enhances the farmer's well-being while not impairing the sustainability of rangeland management.

1 Introduction

Large parts of sub-Saharan Africa, central Asia, Australia, and the Americas consist of (semi-) arid regions with low and highly variable precipitation. The dominant land-use in these areas is livestock farming, which provides the livelihood for one billion people. Due to highly uncertain precipitation, income from livestock farming is very risky. Losses from droughts threaten in particular subsistence farmers in those regions where economic institutions for risk management are scarcely available (Hazell 1992, Nieuwoudt 2000). At the same time, grazing management strategies not well adapted to variations in rainfall cause land degradation and desertification (Westoby et al. 1989, Sullivan and Rohde 2002). According to United-Nations' estimates, 41 percent of the earth is covered by drylands and 24% of this land is degrading (UNCCD2010). This trend will accelerate due to climate change. While desertification is one of the major global environmental problems, it is also a major economic problem, as the worldwide income loss associated with desertification of agricultural land is estimated to be at approximately 42 billion US dollars per year (UNCCD 2010).

Against this background, rain-index insurance has been advocated prominently as an effective and economically sensible means of risk management and poverty alleviation. For example, in 2006 the United Nations World Food Programme and the reinsurance company AXA RE announced that for the first time an entire nation's farmers would be insured against drought (Linnerooth-Bayer et al. 2005, WFP 2006): for Ethiopia, a rain-index insurance contract with a coverage of up to 5.8 million Euros was signed based on rain data of 26 weather stations. Worldwide, there are more than a dozen smaller-scale projects financed by the World Bank to test the implementation of rain-index insurance schemes (Skees and Barnett 1999, Miranda and Vedenov 2001, Hess et al. 2002, Skees et al. 2002, World Bank 2005, Chantarat et al. 2007, United Nations 2007, Barnett et al. 2008, Skees 2008, Berg et al. 2009, Hochrainer et al. 2009). Among the middle- and lower-income countries, Mexico and India have the most developed rain-index insurance programs (Barnett and Mahul 2007).

Under a rain-index insurance program, a pre-specified amount of money is paid to the insurant when a rain index that measures seasonal rainfall on a specified area falls below a pre-specified strike level (Skees and Barnett 1999).[1] A farmer can use such a financial instrument to hedge his income risk if his income is positively correlated with rainfall. As the income of livestock farmers in semi-arid regions is, in most cases, strongly correlated with annual precipitation, rain-index insurance provides effective insurance against income risk in these cases. Rain-index insurance has some advantages compared to traditional crop insurance. Less transaction costs arise since the insurance contract is simple, independent of farmers' behavior, difficult to manipulate, transparent, and easy to monitor (Skees and Barnett 1999, Miranda and Vedenov 2001). However, there is evidence that access for farmers to insurance may have ecologically detrimental consequences. Crop farmers who have financial insurance are likely to undertake riskier production than uninsured farmers – with higher nitrogen and pesticide use (Horowitz and Lichtenberg 1993, Mahul 2001), more soil erosion (Wu 1999), or reduced biodiversity conservation efforts (Baumgärtner 2007, Quaas and Baumgärtner 2008, Baumgärtner and Quaas 2009a). Zeuli and Skees (2005) investigate water management in Australia and point out that weather-based insurance may lead irrigators to consume more water rather than less. Bhattacharya and Osgood (2008) show in a static model of a common property pasture that index-insurance may increase stocking rates. One reason for these findings is that often land management practices which are sustainable, i.e. they are viable over the long-run in both ecological and economic terms, at the same time provide ”natural insurance“, that is, they allow farmers to reduce income risk at the price of some reduction in expected income (Widawsky and Rozelle 1998, Di Falco and Perrings 2003; 2005, Baumgärtner 2007, Di Falco et al. 2007). This is a form of self-insurance (Ehrlich and Becker 1972). Specifically, management of (semi-)arid rangelands through resting part of the pasture in years with high rainfall has been shown to maintain the ecological and economic productivity of the rangeland system over time and, at the same time, to reduce farmers' income risk (Müller et al. 2007, Quaas et al. 2007).[2]

In this study we investigate how the design of the rain-index insurance affects the sustainability of rangeland management in (semi-)arid regions, in particular in Namibia. We focus on a commercial livestock farmer on private rangelands, a prevalent land tenure form in southern Africa. Thus, we study problems of non-sustainable land-use which do not result from common-pool ownerships. We employ a stochastic and dynamic ecological-economic model to assess (i) the benefits of rain-index insurance to farmers, and how these benefits depend on the design of the rain-index insurance, specifically on its strike level, i.e. the rainfall level triggering an indemnity payment; (ii) how the availability of rain-index insurance changes a farmer's choice of grazing management depending on the insurance's strike level; and (iii) what are the long-term economic and ecological consequences of this change. For this purpose, we explicitly include feedback dynamics between the ecological and the economic system.

We show that while the availability of rain-index insurance improves the well-being of risk-averse farmers, it also creates an incentive to manage the land in a less sustainable way. This trade-off depends on the rain-index insurance's strike level: the higher the strike level the stronger are the incentives to choose less sustainable grazing management, while the individual farmer's benefits peak at intermediate strike levels. We conclude that the strike level of rain-index insurances should be set at values much lower than suggested by many previous studies.

The paper is organized as follows. In Section 2, we describe the model. The results are presented in Section 3. Section 4 concludes.

2 Generic model of rangeland ecology and management

We base our analysis on an integrated dynamic and stochastic ecological-economic model which is generic in that it captures essential and general aspects and principles of commercial livestock grazing management in (semi-)arid regions. The basic model was developed in previous analyses of good-practice examples, in particular Karakul sheep farming in Namibia (Müller et al. 2007, Quaas et al. 2007, Baumgärtner and Quaas 2009b). An essential element of good-practice grazing management in (semi-)arid regions, which therefore features prominently in the model, is resting part of the pasture in years with sufficient rainfall. Under such a strategy, livestock numbers are matched with available rangeland forage in years with low rainfall, while a part of pasture is left unused (i.e. rested) in years with sufficient rainfall. To this model, we add here a stylized description of rain-index insurance. The basic structure of the model is presented in Figure 1.

- Figure 1 -

The model is time discrete with annual time steps. This time frame is appropriate as we assume a single rainy season per year, after which the farmer adjusts the livestock number to the available forage.

2.1 Ecological sub-model: vegetation dynamics

We assume a fixed overall farm-size. The vegetation dynamics is mainly driven by two factors: precipitation and grazing. Annual rainfall is measured in units of effective rain events per year, that is the number of rain events per year that are effective in triggering plant growth. For example, in the arid rangeland system of Namibia with mean annual precipitation of 180 mm/a, rain events of more than 15 mm/day are considered effective in this sense. For easier handling a continuous scale is assumed. Intra-annual fluctuations of precipitation, which influence to a high degree the germination and establishment of grasses, are not modeled explicitly to reduce the complexity of the model. Precipitation P is modeled as an independently and identically distributed random variable, following a log-normal distribution, which is adequate for semi-arid areas (Sandford 1982), since it is a right-skewed distribution. Events with low rainfall are frequent, but eventually high-rainfall-events occur. The probability density function is

$$f(P) = \frac{1}{P\,\sigma\sqrt{2\pi}} \exp\left(-\frac{\left(\ln P - \mu\right)^2}{2\sigma^2} \right), \qquad (1)$$

where μ and σ are the mean and the standard deviation of $\ln P$. To describe the vegetation dynamics we consider two characteristics of a single, representative perennial vegetation type: (i) The green biomass G_t comprises the photosynthetic organs of the plant. This is also that part of the plant which serves as forage for the livestock. Apart from current precipitation, the available plant reserves strongly influence the formation of new green biomass G. Hence, a multiplicative interrelation between the "reserve" biomass *R* and the current precipitation is assumed. The green biomass G_t in time step t is given by

$$G_t = w_G P_t R_t \ \text{ for } \ t = 1, \ldots, T. \qquad (2)$$

where w_G is a conversion parameter, indicating the extent to which the green biomass G_t responds to reserve biomass R_t and precipitation P_t . By choosing appropriate units of measurement, one unit green biomass corresponds to the amount of biomass consumed per livestock unit per year. (ii) The „reserve" biomass R_t comprises the non-photosynthetic reserve organs below or above ground which do not serve as forage (Noy-Meir 1982). The dynamics of the reserve biomass is described by the following equation of motion:

$$R_{t+1} = R_t - m\,R_t\,(1 + d\,R_t) + w_R \left(1 - c\frac{S_t}{G_t} \right) G_t\,(1 - d\,R_t) \qquad (3)$$

A fraction m of reserve biomass R_t is lost between the end of one growing season and the beginning of the next due to maintenance respiration and mortality (*m* decomposition rate of the vegetation ($0 \leq m \leq 1$)). The reserve biomass increases by photosynthesis in proportion to the amount of effective green biomass with a proportionality factor w_R. A simple linear density dependence in reserve biomass growth is captured by the factors containing the parameter d, with different density regulation for growth and decomposition. The higher d, the higher the decomposition and the lower is the growth of reserve biomass. In order to determine how growth of reserve biomass R_t is driven by photosynthesis in green biomass G_t we account for the impact of grazing. We assume that the herd size S_t does not have an inherent dynamics, but it is completely determined by precipitation and the chosen grazing management strategy (see paragraph below). Full stocking, $S_t = G_t$, means that all available forage, i.e. all green biomass grown on the rangeland in that year, is used. In this case the growth of reserve biomass by photosynthesis is reduced by a factor $1-c$ with $0 \le c \le 1$. A value of c near 0 (1) indicates a low (high) impact of grazing on the dynamics of the reserve biomass. Hence, the parameter c describes the harshness of grazing. With less than full stocking (that is, with resting some part of the pasture), i.e. $S_t < G_t$, the effect of grazing on the reserve biomass is reduced proportionally.

2.2 Economic sub-model: grazing management, insurance, income, and utility

Grazing management is assumed to follow a ”resting in rainy years“-strategy, where the livestock farmer fully stocks in normal or dry years and stocks below the maximum (that is, gives the pasture a ”rest”) in years with high rainfall. Even under such a strategy the stock numbers are often higher in rainy years (despite the resting) than in dry years. A “resting in rainy years” type of strategy is applied in many good-practice farms in Southern Africa, and belongs to the class of rotational resting (or: rest rotation) strategies, which are well-adapted to and commonly used in (semi-)arid regions (Hanley 1979, Heady 1999, Quirk 2002). The key feature of the ”resting in rainy years“-grazing management strategy is that in dry years the whole pasture is used, while in years with high rainfall, i.e. if actual rainfall in that year exceeds the threshold value of $p^{\mathrm{gr}} \in [0,\infty)$, measured as a percentage of mean annual rainfall $E(P_t)$, a pre-specified fraction $\alpha \in [0,100\%]$ of the pasture is rested, which means that $S_t = G_t(1-\alpha/100\%)$ if $P_t > p^{\mathrm{gr}}\, E(P_t)$ and $S_t = G_t$ if $P_t \le p^{\mathrm{gr}}\, E(P_t)$. Hence, the farmer's grazing management strategy is a rule $(\alpha, p^{\mathrm{gr}})$ that determines whether resting takes place, and to what extent. We assume the farmer chooses a fixed grazing management strategy before first grazing (i.e. in year $t = 0$) and applies this rule in every subsequent year. That way, the herd size in each year can be adapted to the weather condition actually encountered in that year. In order to focus on environmental constraints and risks for grazing management – rather than on market constraints and risks – we assume that the livestock number can be adapted to the desired level at no costs. [3]

Rain-index insurance is modeled as a specific-event contract with a fixed payoff as in Turvey (2001). The insurance provider offers a unit rain-index insurance $(1, p^{\text{ins}})$ with a payoff of 1 if precipitation falls below the „strike", a fixed annual rain level p^{ins} which is measured as a percentage of the long-term mean annual rainfall $E(P_t)$. [4] The farmer then can linearly scale the amount of insurance he buys by choosing the number i of unit rain-index insurances (for simplicity we assume that i is a positive real number). That is, at time $t=0$, the farmer decides about the amount i of insurance that he buys for every year. Thus he gets a payoff of i in any year with rainfall below $p^{\text{ins}}E(P_t)$. The farmer annually pays a premium $b\,i$ to the insurer, where b is the premium for a unit of rain-index insurance. The net payoff I_t^{Ins} in year t from the insurance, i.e. indemnity benefit i minus insurance premium $b\,i$ is $(1-b)\,i>0$ if actual rainfall is below the strike level, $P_t \leq p^{\text{ins}}\,E(P_t)$, and $-b\,i<0$ if actual rainfall is above, $P_t > p^{\text{ins}}\,E(P_t)$. For simplicity, we assume an actuarially fair insurance. That is, the annual unit premium b equals the expected indemnity payoff of the unit insurance in every year, such that the insurance comes at no direct costs for the farmer.

The farmer's annual income from livestock grazing is given by the revenues of selling livestock products such as milk, lamb fur and wool. This income is assumed to arise in proportion to the number S_t of livestock on the farm. Assuming further a constant price for the farm's products and normalizing it appropriately, the farmer's income from livestock products simply equals the number of livestock, S_t. [5] Including the rain-index insurance, the farmer's total net income I_t in year t corresponds to the income from livestock products plus the net payoff from the insurance, I_t^{Ins}. Hence, total net income is

$$I_t = \begin{cases} G_t & \text{if} \quad P_t \leq p^{\text{gr}}E(P_t) \\ (1-\alpha/100\%)G_t & \text{if} \quad P_t > p^{\text{gr}}E(P_t) \end{cases} + \begin{cases} (1-b)i & \text{if} \quad P_t \leq p^{\text{ins}}E(P_t) \\ -bi & \text{if} \quad P_t > p^{\text{ins}}E(P_t) \end{cases} . \tag{4}$$

The farmer's preferences over the uncertain stream of present and future income are described by the following expected intertemporal utility function

$$V = E\left(\sum_{t=1}^{\infty} \frac{1}{(1+\delta)^t} \frac{I_t^{1-\theta}}{1-\theta} \right), \tag{5}$$

where $\theta > 0$ is the farmer's degree of constant relative risk aversion and $\delta > 0$ is his rate of time preference. The expected value $E(\cdot)$ is calculated over the probability distribution of all possible time profiles of future rainfall.

The farmer's decision problem is to choose the constant grazing management strategy $(\alpha, p^{\mathrm{gr}})$ and the constant amount of rain index insurance *i* such as to maximize expected intertemporal utility *V* subject to the stochastic dynamics of the grassland ecosystem as described by Equations (4) and (5) and given the exogenously fixed strike level of the rain-index insurance. Formally, the optimization problem is:

$$\underset{(\alpha, p^{gr}, i) \in [0,1] \times [0,\infty) \times [0,\infty)}{Max} V \text{ subject to conditions (1), (2), (3) (4) and (5).} \qquad (6)$$

2.3 Sustainability criterion

We measure the long-term sustainability of grazing management by employing a measure of strong sustainability, requiring both the farmer's income (as an economic indicator of sustainability) and the stock of reserve biomass (as an ecological indicator of sustainability) to be maintained over the long-term future. Under conditions of environmental risk, it is not possible to guarantee sustainability over the long term with 100% certainty, even with a very conservative grazing management. Therefore, we employ ecological-economic viability as a suitable criterion for strong sustainability under conditions of environmental stochasticity (a general description of the concept is provided by Baumgärtner and Quaas 2009b). *Viability*, loosely speaking, means that the different components and functions of a dynamic, stochastic system at any time remain in a domain where the future existence of these components and functions is guaranteed with sufficiently high probability. For the case of rangeland management we require that predefined threshold levels of the farmer's income, $\overline{I}$, and reserve biomass, $\overline{R}$, shall be obtained at a point T in the far future with sufficiently large probabilities. Formally, the management of a farm, consisting of the grazing management strategy $(\alpha, p^{\mathrm{gr}})$ and the amount of rain-index insurance i, is called sustainable, if the following two conditions hold at some point T in the distant future:[6]

$$\begin{aligned} \mathrm{Prob}(I_T \geq \overline{I}) \geq \overline{q}_I \\ \mathrm{Prob}(R_T \geq \overline{R}) \geq \overline{q}_R \, . \end{aligned} \qquad (7)$$

In the subsequent analysis, we determine the left hand sides of these equations, i.e. the probabilities that certain thresholds of income and the reserve biomass are surpassed. The farm management is sustainable if these probabilities exceed given thresholds $\overline{q}_I$ and $\overline{q}_R$.

2.4 Calibration and simulation method

As the intention of our generic analysis is to provide insights into the general dynamics of managed semi-arid rangelands, rather than to provide exact predictions in a particular case, we use parameter values that are taken from different sources and we then perform a sensitivity analysis by varying the ecological parameters in plausible ranges and analyzing the qualitative behavior of the model. Selection of the ecological parameters is based on Müller et al. 2007. The rainfall data of a typical farm in southern Namibia are used as default parameter values for mean and standard deviation of the precipitation (Müller et al. 2007). The parameters for the discount rate and the degree of relative risk-aversion are chosen according to the results from a survey of 399 Namibian livestock farmers, representing 16 percent of all livestock farmers in the country (Olbrich et al. 2009). Table 1 gives an overview of the parameter values used in the simulations.

- Table 1 -

For the simulations and optimizations we developed specific MATLAB (version R2009a) codes. In order to solve the stochastic and dynamic optimization problem, the MATLAB routine *fminsearch* that uses a Nelder-Mead simplex search method (Lagarias et al. 1998) turned out to be most efficient. Expected values are calculated as averages taken over one million runs.

3 Results: Rain-index insurance and the sustainability of rangeland management

3.1 Result 1: Resting in rainy years as investment and natural insurance

To start with, we ignore rain-index insurance and analyze the role of resting in rainy years for income, income risk and pasture condition. We want to test the following hypotheses: First, both a larger fraction of resting (i.e. a higher value of α) and a lower rain threshold (i.e. a lower value of p^{gr}) means that the strategy is more conservative in the sense that the means of both reserve biomass and income are higher in the long run. Second, the ”resting in rainy years“-strategy provides natural insurance in the sense that it reduces income variability.

- Figure 2 -

Figure **2** shows contour lines of the expected income at time T, $E(I_T)$, for multiple grazing management strategies $(\alpha, p^{gr}) \in [0,100\%] \times [0,240\%]$ and two time horizons ($T=1$ and 70 years).[7] For a very short time horizon ($T=1$), a grazing strategy with little resting, i.e. a low fraction α of rested pasture and a high rain threshold p^{gr}, generates the highest expected income (**Figure 2**a). For a very long time horizon ($T=70$), the qualitative behavior changes strongly (**Figure 2**b). Strategies with an intermediate level of resting generate the highest expected income. This is due to the fact that high livestock number and, consequently, high income can be ensured over the long run only if reserve biomass production is maintained by applying some resting. This is the case for conservative strategies (**Figure 2**d). If the strategy is too conservative, however, the potential of the high reserve biomass in the long-run is not used. Hence, while farmers who apply substantial resting in rainy years do not generate the maximum possible short-term income, they obtain a greater expected income in the long term. That is, resting in rainy years may be regarded as an investment: it increases future expected income at the cost of reduced present income.

How income risk, measured by the coefficient of variation of income at time T, $Sd(I_T)/E(I_T)$, depends on the grazing management strategy is shown in **Figure 2** e and f. For both $T=1$ and $T=70$ the lowest income risk results from medium levels of resting in terms of both rested fraction of land and rain threshold. The reason is that these strategies generate in dry years additional (otherwise rested) pasture. Hence, livestock number has to be reduced less compared to strategies which include almost no resting ($\alpha < 10\%$) or resting in almost each year ($p^{gr} < 50\%$). In other words, the strategy ”resting in rainy years“ involves a natural insurance effect for farm income. Hence, a risk-averse farmer has an incentive to apply such a strategy for the insurance effect it provides.

3.2 Result 2: Rain-index insurance is beneficial for the farmer

Now we study the effects of introducing a rain-index insurance: For a given strike-level p^{ins} of the insurance, the farmer chooses both the amount of rain-index insurance i and the grazing management strategy (α, p^{gr}) such as to maximize expected intertemporal utility *V*. As rain-index insurance obviously changes the statistical characteristics (i.e. mean and coefficient of variation) of income from livestock farming when applying a particular grazing management strategy, the question arises in which way does rain-index insurance change a farmer's choice of the grazing management strategy.

- Figure 3 left, right -

Figure 3 (left graph) shows the optimal amount of insurance *i* as a function of the strike level. The figure shows that it is optimal to choose a lower amount of insurance the more frequently the benefit is received, i.e. the higher the strike level is. The right graph in the figure shows the difference between the net present value of a farmer's utility with and without rain-index insurance. The difference is unambiguously positive, indicating that the availability of rain-index insurance improves the farmer's well-being. The figure also shows that the most beneficial strike level from the farmer's perspective is at about 75% of the long-term mean annual rainfall.
With an actuarially fair insurance, it might be surprising that a farmer would not choose “full” insurance. Rain-index insurance, however, is not a perfect income insurance because rainfall and income are not perfectly correlated. Choosing a very high amount of insurance does not necessarily decrease income risk. With a very high payment in dry years and an accordingly high premium in rainy years it may even reverse the income risk. This holds even more with a grazing management strategy with resting in rainy years.

3.3 Result 3: Rain-index insurance crowds out natural insurance

Figure 4 shows how the availability of rain-index insurances with different strike levels p^{ins} affects the farmer's choice of a grazing management strategy. The solid curve in the graph on the left shows the optimal fraction of resting α with insurance, the solid curve in the graph on the right shows the optimal rain threshold of the grazing management strategy p^{gr} with insurance. The dotted lines show the corresponding values without insurance.

- Figure 4 left, right -

A rain-index insurance with a strike level of up to about 20% of long-term mean rainfall has little effect on the choice of the grazing management strategy. For higher strike levels, the optimal grazing management strategy becomes less and less conservative, as both the optimal fraction of the pasture rested, α, decreases and the threshold p^{gr} above which resting is applied increases. This shows that the rain-index insurance serves as a substitute for the natural insurance obtained from a grazing management with resting in rainy years.

A sensitivity analysis of the preference parameters θ and δ has shown that a lower degree of risk aversion θ or a lower discount rate δ reduce the magnitude of effects observed, while a higher degree of risk-aversion or a higher discount rate increases the effects. The intuitive reason for these results is as follows: A higher degree of risk-aversion increases the need for insurance, thus increasing the trade-off between rain-index insurance and natural insurance. A higher discount rate means that the investment motive for a conservative grazing management strategy becomes less important. Hence, the natural insurance function of a conservative grazing management strategy becomes relatively more important.

3.4 Result 4: The higher the strike level of rain-index insurance the less sustainable is rangeland management

Figure 5 shows how the sustainability of the optimal grazing management strategy depends on the strike level of the rain-index insurance. The figure shows the probabilities that prespecified threshold levels of income (left graph) and reserve biomass (right graph) are reached at the end of a time horizon of 70 years. The threshold for income is set to 50% of the maximal average income, i.e. the income that is obtained from a pristine pasture with the respective grazing management strategy, averaged over rainfall. The threshold for the reserve biomass is set to 50% of the initial reserve biomass of the pristine pasture. The upper (lower) bounds of the shaded areas in the graphs in Figure 5 depict the probabilities for the respective thresholds at 45% (55%) level.[8]

- Figure 5 left, right -

The results basically resemble the finding that with a higher strike level, i.e. a rain-index insurance that pays off more often, the optimal grazing management strategy is less conservative. Accordingly, it is less sustainable in both economic and ecological terms: a higher strike level of the rain-index insurance leads to a lower probability that both the threshold level of income and of the reserve biomass are reached at the end of the 70 year time horizon. The reason that a higher strike level, i.e. an insurance that pays out more often, reduces not only ecological sustainability but also sustainability of farm income, which may seem counter-intuitive at first, is that a higher strike level leads the farmer to choose a less conservative rangeland management strategy (Result 3). This leads to declining ecological conditions and, thereby, to declining income prospects over the long run.

Importantly, the negative effect of the rain-index insurance is comparatively small for low strike levels of up to about 30% of long-term mean rainfall. The reason is that if the insurance pays out not in ”normal“ drought years but only in extreme drought years, the farmer needs to overcome ”normal“ drought years by the natural insurance which includes resting in rainy years. Hence the farmer needs to manage the rangeland in a sustainable way to ensure low income risk. In other words, in this case the financial insurance covers the catastrophic risk layer and the self-insurance covers the lower-level risk layers.

4 Conclusions

We have analyzed the role of rain-index insurance for grazing management in semi-arid rangelands. In particular, we have studied a commonly used grazing management system under which part of the rangeland is rested in years with sufficiently high rainfall. Though in the short run the farmer forgoes income, resting in rainy years generates benefits to the farmer in two respects. First, resting enables to maintain the productivity of the pasture in the long run. Thus, it is an investment that, while carrying short-term opportunity costs, in return generates a higher future income. Second, resting in rainy years reduces income variations over time and, thus, income risk. Hence, it acts as a natural insurance. This creates an additional incentive for farmers to employ sustainable management practices.

Against the background of this well established grazing management system, we have studied the effects of making rain-index insurance available to livestock farmers, as it is currently being advocated by e.g. the United Nations and the World Bank. We have considered the strike level of the rain-index insurance as a policy variable, because this is the part of the insurance contract that could be regulated most easily. There are three major results:

First, the introduction of rain-index insurance improves the farmers' welfare. The individual farmer's benefit of rain-index insurance is highest for an intermediate strike level of about 75% of long-term mean rainfall according to our simulation results.

Second, natural insurance by a conservative grazing management strategy and financial rain-index insurance serve as (imperfect) substitutes for the farmers' risk management. As a result, the introduction of rain-index insurance leads to the choice of grazing management strategy that provides less natural insurance and that is less sustainable in the long run.

Third, for strike levels that are below, but still relatively close to, long-term mean annual rainfall (over 30% of long-term mean annual rainfall in our analysis) there is a trade-off between the individual farmer's well-being and sustainability. Increasing the strike level increases the farmer's well-being, but reduces the sustainability of rangeland management both in economic and ecological terms. Thus, while our study predicts poor environmental outcomes if rain-index insurance is introduced in its presently advocated form with a relatively high strike level, our study also suggests modifications in the insurance design that will alleviate these problems. If the strike level is set at a level significantly below long-term mean annual rainfall – below 30% of long-term mean annual rainfall in our analysis – so that the indemnity payment is granted only in years of severe droughts, a rain-index insurance brings considerable benefits to the farmer, while not impairing the sustainability of rangeland management. The reason is that with a low to medium strike level resting in rainy years remains an important strategy to reduce income risk by natural insurance to overcome not-so-severe droughts when the insurance would not pay out. So, the adverse incentives from introducing rain-index insurance can be minimized if the insurance scheme is designed accordingly, in particular if the strike-level is lowered considerably compared to current levels. This conclusion contrasts with previous suggestions of much higher strike levels. For example, Turvey (2001) assumed a strike of 95% of long term mean annual rainfall and (Skees et al. 2002) use 67%.[9]

In our study, we have focused on a single risk – namely that of precipitation – and the interplay between two coping strategies – natural insurance through resting the rangeland and financial insurance from a rain index insurance. Most livestock farmers, though, face other risks as well, relating to e.g. input costs, commodity price risks or livestock diseases; and they can employ other coping strategies, such as e.g. supplementary feeding or forward trading on commodity markets. As long as these other risks are uncorrelated with precipitation, taking them into account would qualitatively not change our results. If, in contrast, some of them should be correlated with precipitation, a more detailed analysis is necessary, which is beyond the scope of this paper.

A general conclusion from our study is that if socio-economic institutions for managing income risk, such as rain-index insurance, are designed for introduction into systems where farmers have thus far relied largely on risk mitigating measures through particular forms of ecosystem management ("natural insurance"), as millions of farmers do in many developing countries, the incentives for farmers to change their management strategies when insurance becomes available have to be kept in mind. In particular, policy makers should be aware of the unintended effects when designing policies to support these insurance products, for example by subsidies. Only an explicit consideration of the ecological-economic feedback dynamics avoids negative consequences on the state of ecosystems and, thereby, on farmers' economic wealth in the long-run.

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Table 1: Parameter values used in the analysis.

Parameters	Symbol	Values
Growth rate of green biomass	w_G	1.2
Growth rate of reserve biomass	w_R	0.2
Strength of density dependence	d	0.000125
Impact of grazing	c	0.5
Mean annual rainfall	$E(P_t)$	1.2
Standard deviation of annual rainfall	$SD(P_t)$	0.7
Risk aversion	θ	2.0
Time horizon	T	25 years
Discount rate	δ	12.5% p.a.

Figure captions:

Figure 1: Schematic representation of the model structure. The indemnity payment of the insurance is independent of livestock level or grazing strategy, it depends only on current precipitation. Hence, the effect of precipitation is threefold: It determines the growth of the vegetation, whether resting takes place in the considered year and whether the rain-index insurance pays out. Vegetation dynamics is shaped by rain and grazing history. For further details it is referred to the explanation in paragraph 2.1.

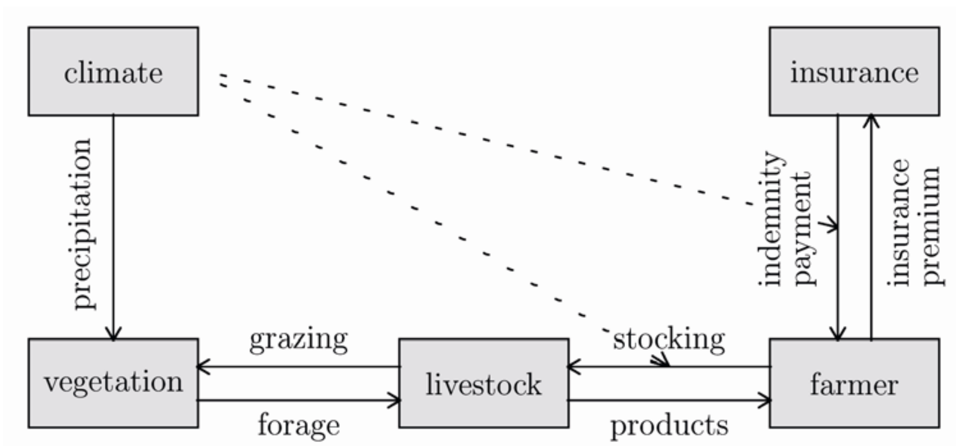


Figure 2: Contour lines of expected income $E(I_T)$ (a,b), of expected reserve biomass $E(R_T)$ (c,d) and of coefficient of variation of income $CV(I_T) = SD(I_T)/E(I_T)$ (e,f) at times T = 1 (for reserve biomass T = 10) and T = 70 over 30,000 simulation runs, for different strategies characterized by the fraction of resting α (in percent) and the rain threshold p^{gr} (in percent of mean annual rainfall). Lighter (darker) shades of grey indicate lower (higher) values of $E(I_T)$, $E(R_T)$ and $CV(I_T)$.

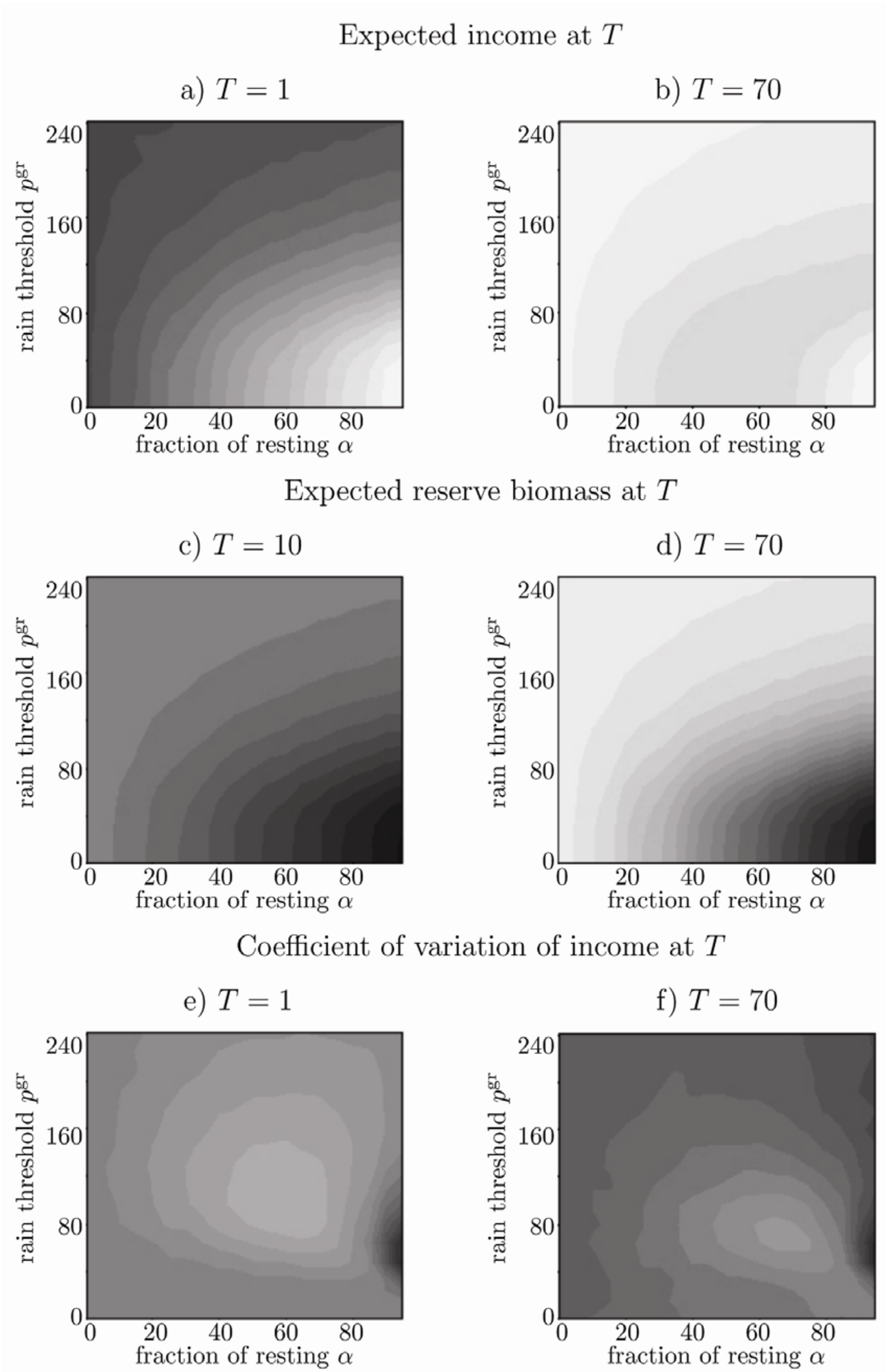
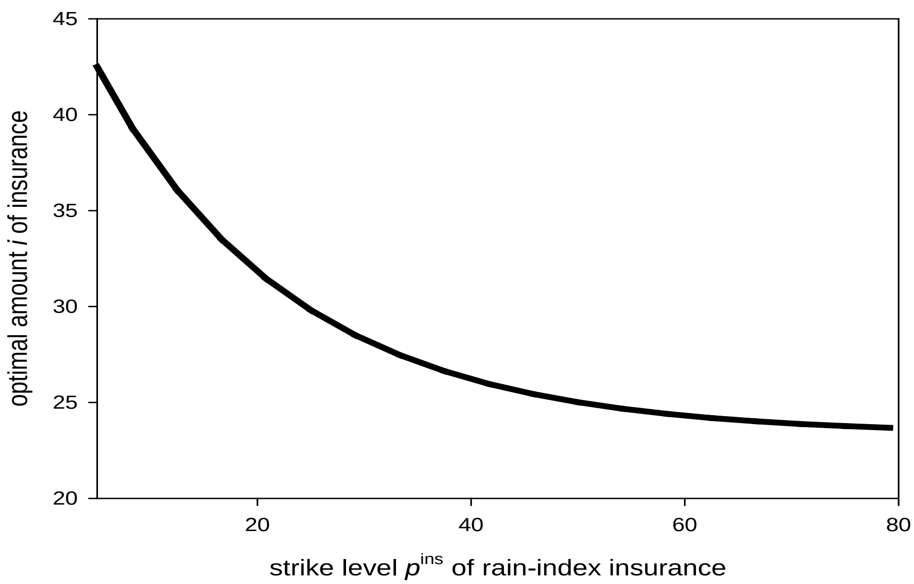

Expected income at T
a) $T = 1$
b) $T = 70$
Expected reserve biomass at T
c) $T = 10$
d) $T = 70$
Coefficient of variation of income at T
e) $T = 1$
f) $T = 70$
rain threshold p^{gr}
fraction of resting α
0
20
40
60
80
160
240

Figure 3: Optimal amount *i* of rain-index insurance (left), measured as a percentage of the maximal average income, i.e. the average income that could be obtained from a pristine pasture with full stocking, and the difference between the expected present value of utility (*V*) with and without rain-index insurance (right) as a function of the strike level p^{ins} of rain-index insurance.



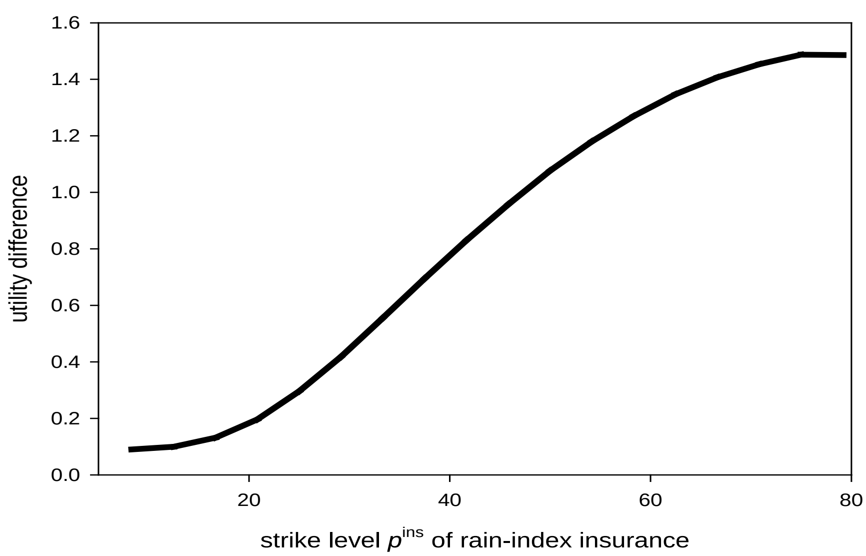
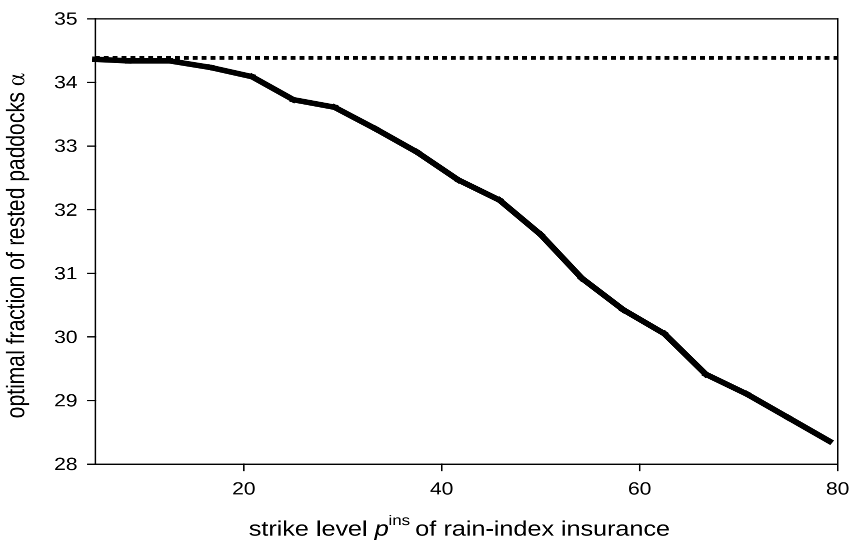


Figure 4: Optimal fraction α of resting, measured as a percentage of the total pasture, for different strike levels p^{ins} of the rain-index insurance (left), where the dotted line denotes the optimal fraction of resting without rain-index insurance, and the optimal rain threshold p^{gr} of the grazing management strategy (right), measured as a percentage of mean rainfall, where the dotted line denotes the optimal rain threshold without rain-index insurance.



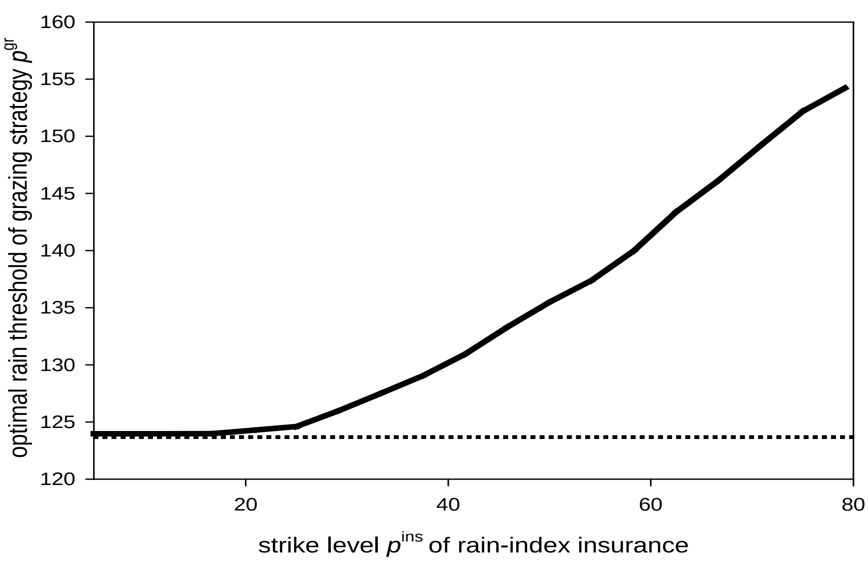
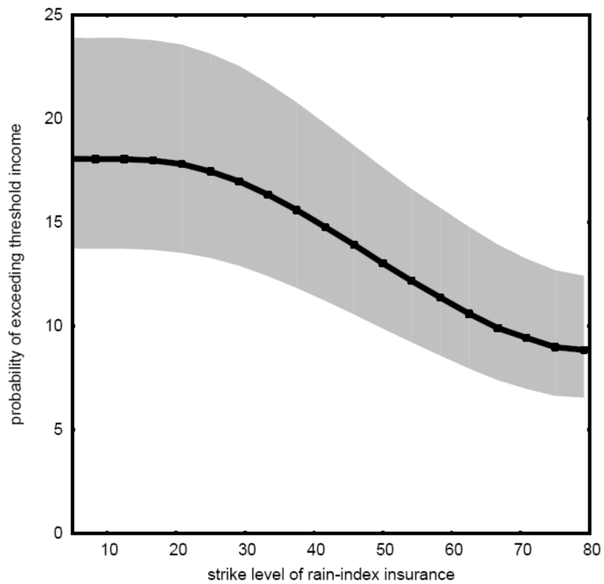
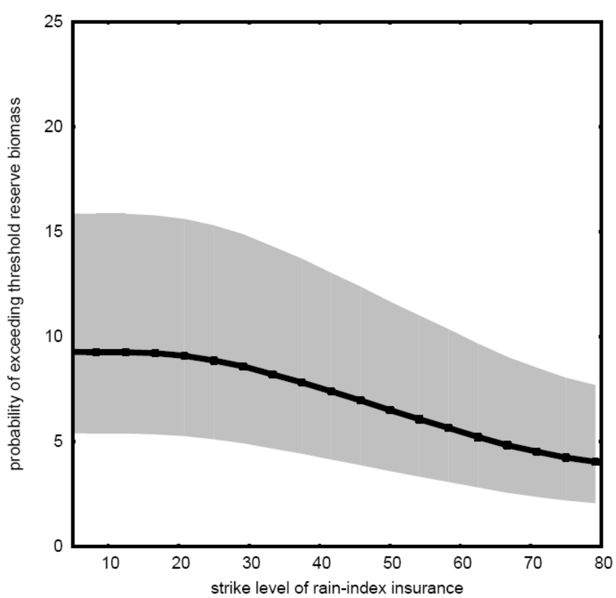


Figure 5: Sustainability of rangeland management as a function of the rain index insurance's strike level. Sustainability is measured as the probability (in percent) that 50% of maximal average income (left) and 50% of maximal reserve biomass (right) are reached at the end of the time horizon, T = 70 years. The upper (lower) bounds of the shaded areas depict the probabilities for the respective thresholds at 45% (55%) level.





Notes:

[1]From a financial economics point of view, a rain-index "insurance" is a specific weather derivative rather than an insurance in its proper sense. Weather derivatives are traded in the USA since 1997, mostly based on temperature-related "assets", such as Heating Degree Days or Cooling Degree Days (Garman et al. 2000). It is a call option with a fixed payoff which the farmer, who is long such a call, receives in case the value of the asset falls below the strike level.

[2] Alternative grazing management strategies to cope with highly variable and uncertain precipitation, that are actually employed in Southern Africa, include matching the stocking rate with available forage in every year ("opportunistic strategy"), resting the rangeland during (or immediately after) periods of extreme drought ("resting in drought years"), or a low constant stocking rate in all years. Elsewhere, we have demonstrated through a model analysis that the "resting in rainy years"-strategy is indeed optimal if the state of the rangeland is not extremely good and if rainfall is within reasonable limits (Quaas and Baumgärtner 2011), and if the speed at which livestock can be rebuilt is not so low that unplanned rests predominate the effect of "resting in rainy years" (Müller et al. 2007). Whether resting is optimal at all depends on the farmer's risk aversion and myopia: with a short time-horizon and a low degree of risk aversion it may be optimal to not rest the rangeland at all (Quaas et al. 2007).

[3] Technically, this assumption can be vindicated by assuming that the farmer annually rents his livestock on a perfect rental market for livestock. If the farmer owns a constant herd of size S_0, he would rent a number S_t-S_0 if $S_t>S_0$ or rent out a number S_0-S_t if $S_t<S_0$. Without loss of generality, we set $S_0=0$. This allows the farmer to exactly adapt the actual herd size to the available forage and to his chosen grazing management strategy. Hence, as already stated, the herd size S_t does not follow its own dynamics, but it is completely determined by precipitation and the chosen grazing management strategy. Although in Namibia spatial correlation of rainfall is relatively low, it may be more realistic to assume that lease prices for livestock are correlated with rainfalls such that lease prices are higher in rainy years when demand is high than in dry years when demand is low. A thorough analysis of lease livestock prices

correlated to rainfall (as performed for a different context by e.g. Hein and Weikard 2008, Weikard and Hein 2011), however, is beyond the scope of this paper.

[4]In general, the insurance strike level p^{ins} is different from the threshold p^{gr} above which stocking is reduced under the grazing management strategy (α, p^{gr}).

[5] In our analysis we neglect uncertainty of prices. In Namibia, many products of livestock farming are sold at international or even world markets. Thus, price uncertainty is likely to be uncorrelated to local rainfall. Including a price stochasticity uncorrelated to rainfall would not significantly alter our results. For farmers who sell their products on local markets, the prices are perhaps more likely to be correlated to rainfall. The inclusion of price stochasticity correlated to rainfall, however, is beyond the scope of this paper (see also footnote 3).

[6]If the sustainability criteria are fulfilled at time T, they are necessarily fulfilled also in the nearer future, i.e. at any time $t \leq T$, as initially the pasture is in a pristine state and the reserve biomass gradually declines with grazing.

[7] Note that in contrast to the following section these results are not based on any optimization but rather illustrate the effects of different grazing management strategies.

[8] We conducted a similar sensitivity analysis with respect to the threshold levels of income and reserve biomass, which we do not present here, as the results are very similar to the sensitivity analysis with respect to the probability thresholds.

[9] If for some reason a low strike level is not desired, sustainability of rangeland farming might also be ensured by requiring insured farmers to comply with minimum resting standards. A comprehensive analysis of the effects of such compliance standards on the farmer's welfare and the effects of rain-index insurance under such a scheme are beyond the scope of the present paper, however.