Risk management in a semi-arid rangeland system - the role of rain-index insurances

BIRGIT MÜLLER[1*], Martin Quaas[1], Stefan Baumgärtner[2], Karin Frank[1]

[1] Department of Ecological Modelling, UFZ, Helmholtz Centre for Environmental Research - UFZ, Leipzig, Germany

[2] Centre for Sustainability Management, University of Lüneburg, Germany

[*] Corresponding author: UFZ, Helmholtz Centre for Environmental Research - UFZ, Department of Ecological Modelling, P.O. Box 500135, D-04301 Leipzig, Germany. Email: birgit.mueller@ufz.de

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Abstract

The livelihood of the majority of people in (semi-)arid regions depends on livestock farming. Inappropriate grazing strategies can lead to land degradation, i.e. loss of pasture productivity. Moreover, the highly variable and uncertain precipitation translates into a highly uncertain income. Rain-index insurance provides the possibility of hedging income risk.

This study investigates how the access to rain-index insurance influences the grazing strategy of a farmer. The starting point for the analysis of different grazing strategies is the case study of a farm in Namibia successful in ecological and economic terms. With the help of an ecological-economic model, the farmer's choice of a grazing strategy with and without insurance is compared. The decision criterion applied is a safety-first rule.

The results show that resting during wet years acts as a risk reducing strategy. Furthermore, it enables the farmer to maintain high pasture productivity over the long term. However, a farmer with access to insurance may change the grazing strategy towards less resting. The influential factors in this respect are his attitude towards risk and time horizon.

Policy makers should be aware of the influence of economic risk management measures, such as insurances, on farmer's choice of grazing strategies, since they may have detrimental effects on the productivity of the rangeland ecosystem and, hence, on the long-term well-being of farmers. Therefore, an analysis including explicitly ecological and economic feedback mechanisms of the land use system is a prerequisite.

1 Introduction

A third of earth's land surface consists of (semi-)arid regions. The livelihood of a vast majority of people in these areas is earned by livestock farming. Due to the highly variable and uncertain precipitation the income gained by livestock farming is very risky. Large livestock losses resulting from long lasting droughts threaten particularly subsistence farmers in those regions where economic institutions for risk management are scarcely available (Hazell, 1992; Nieuwoudt, 2000).

In the USA for over one hundred years crop insurances are offered in agriculture to manage risk. Farmers who have bought such insurance receive a payment depending on the experienced loss. The asymmetric information distribution of farmers and insurance enterprises leads to classical insurance problems such as moral hazard and adverse selection (for an example see Luo *et al.*, 1994). Additionally, sufficient and reliable historical data of farm yields are often not available to calculate a fair insurance premium. In order to cope with these problems, insurance premiums have to be either extremely high or highly subsidized by the government. Hence, in the vast majority of cases, agricultural insurances are not profitable and if they are, private insurers serve predominantly large-scale commercial farms growing high-value crops (Hazell, 1992).

One method for avoiding these classical insurance problems is to offer index-based insurances (Skees & Barnett, 1999). The payoff of the insurance does not depend on individual farmer's behaviour, but on an index on the prior specified area. Two forms are distinguished (Hazell, 1992; Miranda & Vedenov, 2001): area-yield indices and rain indices. In the first case the payoff is granted when the livestock yield on a regional scale does not reach a prior specified limit (Miranda, 1991; Skees *et al.*, 1997). In the second case, the insurance pays out whenever precipitation is below a predetermined level.

From a financial economics point of view, a rain-index insurance is a specific weather derivative. Weather derivatives are traded in the USA since the summer of 1997, mostly based on temperature-related "assets", as Heating Degree Days or

Cooling Degree Days (Garman *et al.*, 2000). A rain-index insurance is obviously based on precipitation, with a certain amount of money associated with rainfall below a defined strike. It is a call option with a fixed payoff, which the farmer, who is long such a call, receives in case the season's precipitation is below that strike. The farmer can use such an an insurance to hedge his income risk, if his income is positively correlated with rainfall. In this case, it serves as an insurance.

Thus, for index based insurances no data at the farm level are required. Since the income of livestock farming in semi-arid regions is, in most cases, strongly correlated to the annual precipitation, the focus in this study is set on the second form of index-based insurances - on rain-index insurances.

Currently, numerous studies by the World Bank are being carried out worldwide to investigate the feasibility of rain-index insurances, for instance in Morocco, Mexico, Nicaragua, Uruguay (Skees & Barnett, 1999; Miranda & Vedenov, 2001; Skees *et al.*, 2002; Wenner & Arias, 2003). In Ukraine, Malawi, India and Nicaragua pilot projects are already in the phase of implementation (Hess *et al.*, 2002; McCarthy, 2003; WorldBank, 2005; UN, 2007). In March 2006 United Nations World Food Programme and the reinsurer AXA RE issued an index-based insurance policy for Ethiopia which was discussed in the media worldwide. For the first time an entire nation's farmer were insured against extreme drought. (WFP, 2006). In Ontario (Canada) rainfall insurances have been in practise since 2000 (Turvey, 2001).

This type of insurance has been recently received more attention in the literature: Studies exist which deal with the issue of developing and pricing such a form of rain-index insurances (Martin *et al.*, 2001), designing optimal insurance contracts (Mahul, 2001) or empirical studies which are aimed at estimating the demand for rain-index insurances (Patrick, 1988; Sakurai & Reardon, 1997).

Rain-index insurances have been proposed as an alternative to traditional insurances, with the argument that less transaction costs arise (Skees & Barnett, 1999; Miranda & Vedenov, 2001). The insurance contracts based on trigger rain events are simple, independent of farmer's behaviour, difficult to manipulate, transparent, and easy to monitor. Thus, they involve numerous advantages: The simple form of the contracts raises the acceptance in areas where farmer are less educated. It can be tailored to the specific needs of the customers (Skees & Barnett, 1999; Turvey, 2001). Secondly, problems resulting from asymmetric information such as moral hazard and adverse selection can be avoided. Thirdly, the transparency of index-based contracts and their independence from major financial markets both make the contracts attractive for foreign investors and allow insurers to transfer the systemic component of insurer's risk to the global market (Miranda & Vedenov, 2001). These authors, furthermore, point out the additional advantage that agribusinesses, which are indirectly affected by weather risk, may also buy such forms of insurance policies as input supply, transportation, storage, processing, marketing, banks, governments.

Nevertheless, certain challenges exist: This form of insurance is only suitable where income risk is strongly correlated to rainfall. Furthermore, since by construction the insurance benefits do not depend on the individual farmer's losses in a particular year, the rain-index insurance does not ensure a minimal income level for individual farmers. The remaining risk is generally referred to as basis risk (Miranda & Vedenov, 2001). The geographical basis risk can be minimised by a sufficiently dense net of rainfall measurement points and the availability of contracts, wherein the farmer can spread out his risks based on several surrounding weather stations (Martin *et al.*, 2001; Turvey, 2001). Since rainfall in semi-arid regions is often very heterogeneously distributed, this dense net is necessary. Modern satellite imagery may further help to monitor and assess soil moisture (Hazell, 1992).

One advantage of rain-index based insurance, which has been emphasized, is that it does not suffer from moral-hazard problems. This is true by construction of the rain-index based insurance, as long as only the contract between the insurant and the insurance provider is considered. From a broader perspective, the rain-index based insurance will nevertheless have an influence on the farmer's actions. In particular, he may operate his farm in an ecologically less sustainable way. Horowitz & Lichtenberg (1993) found that farmers who are provided with an index-based insurance are likely to undertake riskier production - with higher nitrogen and pesticide use - than uninsured farmers do. A similar result is pointed out in Mahul (2001), assuming a weather-based insurance. Wu (1999) estimates in an empirical study the impact of insurances on the crop mix and its negative results on soil erosion in Nebraska (USA).

The present study is concerned with the question how the access to rain-index insurances affects the sustainability of grazing strategies applied by farmers in semi-arid rangelands. In particular, we want to test the hypothesis that farmers who have signed an insurance contract choose less sustainable grazing strategies than they would without the contract (Baumgärtner & Quaas, 2006; Quaas & Baumgärtner, 2006; Baumgärtner, 2007).

Why is an appropriate grazing strategy so crucial in semi-arid ecosystems? Degradation, i.e. the loss of productive land, is a major danger for these regions. A fifth of the world's drylands, or around a billion hectares, and an estimated 250 million people (UNCCD, 2004) are affected by human-induced soil erosion. The scientific debate goes on about the causes (Cowling, 2000; Briske *et al.*, 2003). Current research points out that grazing strategies have to be adapted to temporal and spatial heterogeneous forage production (Westoby *et al.*, 1989; Sullivan & Rohde, 2002). Furthermore, the role of rest periods for the pasture after droughts or in rainy years is emphasised to maintain the persistence and productivity of the rangeland system (Müller *et al.*, 2007). In that study it was additionally shown that strategies which grant a rest period in rainy years act as a risk-reducing strategy for income. Hence, the supposed hypothesis can be specified: Access to rain-index insurances is supposed to lead to fewer rest periods in rainy years. The reason is that with insurance the farmer can better cope with dry years, and strategies which grant rests in rainy years and generate a reserve are no longer necessary to meet the selected objective.

In Quaas *et al.* (2007) the role of the risk attitude of the farmer on the choice of the grazing strategy is investigated. The study reveals that the more risk-averse a farmer is the more sustainable is his grazing strategy independently of his time horizon. Hence, the hypothesis is that risk management strategies (such as rain-index insurances) which reduce income risk lead to less sustainable strategies.

For the investigation we use an abstract ecological-economic model to compare the farmer's choice of a grazing strategy with and without insurance. Furthermore, it is aimed to investigate the impact of the resultant grazing strategy on the long-term productivity of the pasture. In this model the feedback dynamics between the ecological and economic system are included. The starting point of the analysis is a farm in Namibia that is successful in ecological and economic terms - the Gamis Farm. This is a Karakul sheep farm, which applies resting for a third of the pasture in years with sufficient rainfall. This case study is well studied from an ecological perspective (Stephan *et al.* 1998; Müller *et al.* 2007) and an ecological-economic perspective (Quaas *et al.* 2007).

The Gamis Farm is situated 250 km southwest of Windhoek in Namibia (24°05'S 16°30'E) in the district Maltahöhe close to the Naukluft mountains at an altitude of 1250 m. The climate of this arid region is characterised by low annual precipitation (177 mm/y) which is highly variable in space and time. The coefficient of variation is 56%. The vegetation type is classified by Giess (1998) as dwarf shrub savanna. Detailed information regarding the climatic, edaphic and botanical setting of the study site can be found in Maurer (1995).

Karakul sheep (race Swakara) are bred on an area of 30 000 hectares. The primary source of revenue is from the sale of lambskins. Additionally, the wool of the sheep is sold and meat is used for farm consumption (Tombrink, 1999). In good years, up to 3000 sheep are kept on the farm. For forty years, an adaptive management system has been tracking the variability in forage. During this time detailed records were kept by the owner, H.A. Breiting. The basis of the system is a rotational grazing system: The pasture land is divided into 98 paddocks; a paddock is grazed for a short period (about 14 days), after which it is rested for a minimum of two months. This system puts high pressure on the vegetation for a short time in order to prevent selective grazing. Moreover, the farmer has introduced an additional rest period: One third of the paddocks is given a rest during the growth period (September - May). Outside this period, all paddocks are grazed. In the literature this strategy is termed rotational resting (Heady, 1999; Quirk, 2002; Stuth & Maraschin, 2000) or rest rotation (Hanley, 1979). The Gamis Farm strategy is distinct from simple rotational resting systems in that rest periods are granted only in years with sufficient precipitation. In years with insufficient rainfall this rest period is reduced or completely omitted. Further measures, such as renting of additional pasture, are taken during long periods of drought. Once a year at the end of the rainy season (April), the farmer decides how many of the lambs will be raised and whether additional land will be rented from farms elsewhere in the country (H.A. Breiting, pers. comm.). For a complete and detailed description of the grazing system see Stephan *et al.* (1996, 1998).

The grazing management system employed at the Gamis Farm has been successful over decades, both in ecological and economic terms. Therefore, it represents a model for commercial farming in semi-arid rangelands.

There is currently no rain-index insurance available in Namibia. With the help of the ecological-economic model, which is developed in the following section, we are in a position to assess how the introduction of such an insurance could change the sustainability of grazing management on farms like Gamis.

The remainder of the paper is structured as follows: In the following section, the ecological-economic model is presented. Subsequently, the effects of grazing strategy and rainfall on income and biomass production over time are studied. Afterwards the impact of the decision criteria - safety-first rule - on the grazing strategy with and without access to rain-index insurances is investigated, as well as the consequences for pasture productivity. The impact of different ecological and climatic conditions is analysed subsequently. In the discussion section the acquired results are interpreted. Furthermore, the appropriateness of safety-first rules for decision making and of rain-index insurances as risk management measures is discussed.

2 The model

2.1 Structure of the model

Our study aims to analyse how availability of index-based insurances change the grazing strategies of an individual farmer. We assume that he decides on the basis of a safety-first decision criteria (see Section 2.5.1). We analyse the role of farmer's preferences, time horizon and of ecological and climatic settings on the chosen strategy. Furthermore, we investigate the impact on the rangeland ecosystem.

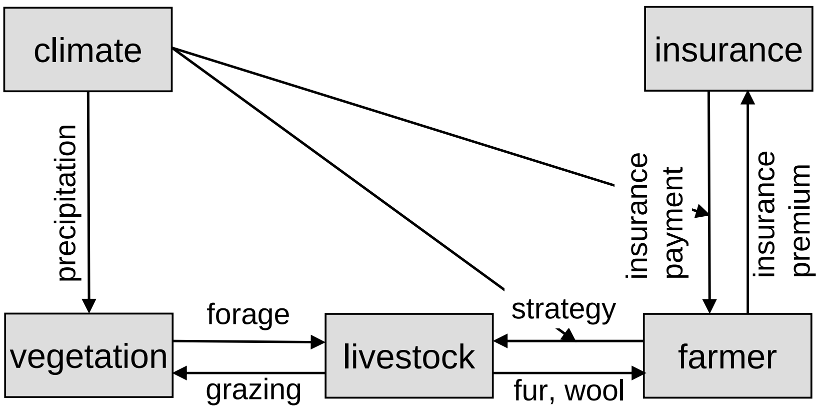


Figure 1: Schematic representation of the ecological-economic system

The main aspects of the ecological-economic model are presented in Figure 1. The vegetation dynamics is driven by two factors: precipitation and grazing. Other factors like plant-available nutrients and fire can be neglected, since they play only a minor role in the type of ecosystem under consideration.

The number of livestock on the farm and, hence, grazing pressure, depends on the chosen management strategy. If the farmer embarks on the strategy "resting in wet years", he determines whether some paddocks are rested, according to current rainfall. Otherwise, the livestock number is adjusted to the available forage. The surplus of livestock are slaughtered or sold. If an insurance contract is signed, the farmer receives an indemnity payment, when a weather trigger event falls short. In each year the farmer pays the insurance premium.

2.2 Precipitation

Precipitation in arid regions is characterised by a low mean, and high spatial and temporal fluctuations. To simulate these properties the precipitation is modelled stochastically, following a log-normal distribution (Sandford, 1982). This is a rightskewed distribution: events with low rainfall are frequent, but eventually high-rainfall-events occur. The distribution of precipitation p_t is characterised by its mean $E(p)$ and its standard deviation $\sigma(p)$. The units of the measurement indicate the number of effective rain events per year (on Gamis Farm: events of more than 15 mm): For instance value 2 signifies 2 effective rain events. For easier handling a continuous scale is assumed.

2.3 Vegetation dynamics

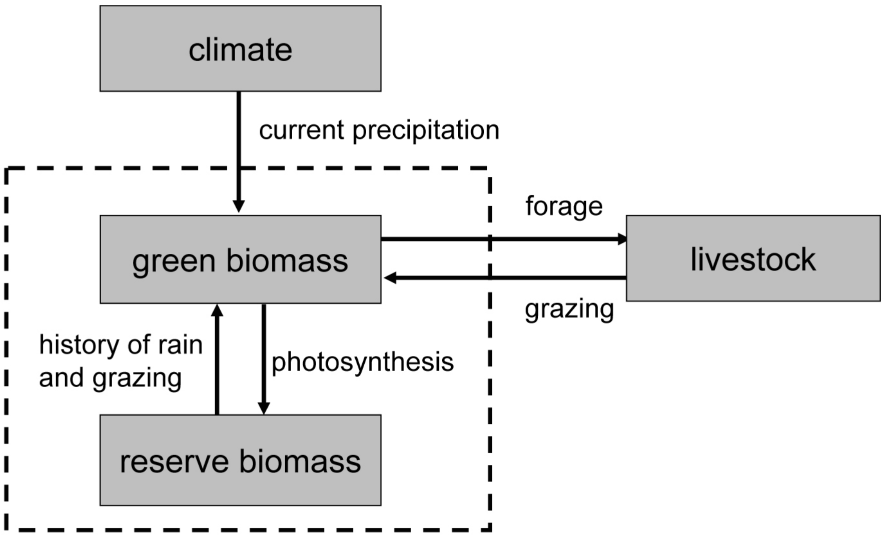


Figure 2: Causal diagram of the submodel vegetation dynamics

For the vegetation dynamics a conceptual, highly abstract model with two relatively simple difference equations was used.[1] Two characteristics of a single, representative perennial vegetation type are distinguished in order to capture that current biomass does not only depend on current rainfall p_t but on grazing and rainfall history as well: The green biomass G_t describing the photosynthetic organs of the plant and being that part of the plants which serves as forage for the livestock; secondly the reserve biomass R_t (termed after Noy-Meir, 1982) describing the non-photosynthetic reserve organs below or above ground (cf. Figure 2). 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 or mortality). The reserve biomass R_{t+1} increases by photosynthesis depending on the amount of available green biomass G_t. The increment of the reserve biomass R_{t+1} is different, if a paddock is grazed or if it is rested. The extent to which new reserve biomass R_{t+1} is accumulated from green

[1] The vegetation and sheep dynamics are described in detail in Müller *et al.* (2007).

biomass G_t by photosynthesis is described by the growth rate of reserve biomass w_{res}. The impact of grazing is captured by the parameter $0 \leq c \leq 1$, where a c near 0 (1) indicates a low (high) impact of grazing. The relationship leads to:

$$R_{t+1}^i = \begin{cases} R_t^i - m \cdot R_t^i \cdot (1 + d \cdot R_t^i) + w_{res} \cdot (1-c) \cdot G_t^i \cdot (1 - d \cdot R_t^i) \\ R_t^i - m \cdot R_t^i \cdot (1 + d \cdot R_t^i) + w_{res} \cdot G_t^i \cdot (1 - d \cdot R_t^i) \end{cases} \tag{1}$$

where the upper expression applies if paddock i is grazed and the lower one, if it is rested. Equation (1) described the dynamics of the reserve biomass for all time steps t, $t = 1, \ldots, T$, and for all paddocks i, $i = 1, \ldots, n$, where T indicates the farmer's time horizon and n the number of paddocks on the farm. A density dependence in reserve biomass growth is captured by the factors containing the parameter d. The higher d, the higher is the consumption and the lower is the growth.

The green biomass G_t^i of paddock i in time step t is given by

$$G_t^i = w_{gr} \cdot p_t \cdot R_t^i \qquad \text{for} \quad i = 1, \ldots, n \quad \text{and} \quad t = 1, \ldots, T. \tag{2}$$

Here, the parameter w_{gr} is a conversion parameter, indicating the extent to which the green biomass G_t responds to reserve biomass R_t and current plant-available water p_t.

2.4 Livestock dynamics and grazing strategy

Without insurance, the farmer's annual income I_t is given by the revenues of selling lambskins and sheep wool. This income is assumed to arise proportional to the number of livestock S_t on the farm. Further assuming a constant price for the farm's products and normalizing it appropriately, the farmer's income simply equals the number of livestock, $I_t = S_t$.

Before first grazing in year $t = 0$, the farmer chooses a grazing strategy which is afterwards applied the whole time. He decides how much and when resting is granted for the pasture. By assumption, resting is carried out only in rainy years. Thus, the farmer's grazing strategy, indicated by $(\alpha, \hat{p})$, is characterised by two attributes:

- portion of the pasture rested α, varying from 0 to 100%.
- rain threshold $\hat{p}$, above which a part of the pasture is rested.

Additionally, in each year the current stocking rate S_t is limited by available forage G_t on pastures not rested. For simplicity, we assume that the livestock number can be adapted to the desired level at no costs.

2.5 Insurance

The rain-index insurance is realised as follows. If precipitation falls short of a fixed annual rain level p^* (notice: p^* is independent of $\hat{p}$), the farmer receives an indemnity payment i. On the other hand, he annually pays a premium b to the insurance. Thus the income of the farmer I_t in year t corresponds to the number of sheep S_t on the farm decreased by the premium b augmented by the payoff i in years with bad rain:

$$I_t = \begin{cases} S_t - b + i & \text{if } p_t \leq p^* \\ S_t - b & \text{if } p_t > p^* \end{cases} \tag{3}$$

We assume an actuarially fair insurance. That means that the premium b the farmer has to pay each year is equal to the expected payoff of the insurance:

$$b = i \cdot P(p_t \leq p^*) \tag{4}$$

The insurance offers one specific insurance contract (i, p^*). At time $t = 0$ the farmer decides whether to sign the insurance contract or not. This decision is retained for the whole time span.

2.5.1 Decision making - Safety-first rule

The farmer's preferences are described by a safety-first rule (Roy, 1952; Telser, 1955; Kataoka, 1963): the primary goal is to reach a certain minimal income in each year. We use the criterion introduced by Telser (1955): Firstly, the decision maker determines the set of strategies, for which the probability of falling short a certain minimal level of income does not exceed a tolerated risk level. In the next step, out of this set of admissible strategies, the mean income is maximized. Formally, this leads to

$$\max_{(\alpha,\hat{p})} E(I) \text{ subject to } P((I) \leq I_{min}) \leq P_{tol} \tag{5}$$

with $(\alpha, \hat{p})$ indicating the grazing strategy, I_{min} the minimal level of income, and P_{tol} a tolerated risk level of failing target I_{min}. Risk aversion is defined here in the following sense: Farmer 1 is "more risk averse" than farmer 2, if he has higher minimal income level assuming the same tolerated risk level (i.e. $I^1_{min} > I^2_{min}$ and $P^1_{tol} = P^2_{tol}$) or if he tolerates only a lower risk level assuming the same minimal income (i.e. $P^1_{tol} < P^2_{tol}$ and $I^1_{min} = I^2_{min}$).

Describing preferences in this way seems to be more appropriate in an agricultural context, where decision makers tend to reach a certain safety level, than using an expected utility function. Agricultural economists have applied the safety-first decision criterion to problems ranging from soil conservation (Shively, 1997, 2000), fertiliser use (de Janvry, 1972; Van Kooten *et al.*, 1997), cropping systems (Adubi, 2000; Watkins *et al.*, 2004) to air pollution (Qiu *et al.*, 2001).

Telser's decision rule is coined for static decision problems under uncertainty. For the sake of our dynamic analysis, we modified Telser' Safety-First Rule as follows. Firstly, the probability that income falls short of a given, and constant, threshold I_{min} has to lie below a given, and constant, tolerated risk level P_{tol} in each year from the presence $t = 1$ to the end of the time horizon at $t = T$. Secondly, out of the set of strategies which fulfill this constraint, that one is chosen, which maximizes the expected value of average annual income, with zero discount rate, over the whole time horizon. Formally, the farmer's decision problem without access to insurance is

$$\max_{(\alpha,\hat{p})} E(\frac{1}{T}\sum_{t=1}^{T} I_t) \text{ subject to } P((I_t) \le I_{min}) \le P_{tol}, \ \forall t = 1, \cdots, T, \tag{6}$$

where $I_t = S_t$ is the farmer's income at time t.

Introducing the rain-index insurance, we assume that the rain threshold p^* below which the insurance pays out is a fixed proportion of the long term mean of rainfall (cf. Turvey, 2001; Skees *et al.*, 2002). Firstly, the insurance company offers a fixed insurance contract, e.g. ($i = 200, p^* = 0.75$). This signifies that 200 units are paid out in case rainfall is below 75% of long term mean.[2] In this case, additionally to the choice of the grazing strategy $(\alpha, \hat{p})$, the farmer decides whether he signs this specific insurance contract ($V = 1$) or not ($V = 0$). This decision is made once prior to first grazing and, afterwards, holds true for the whole time horizon. The farmer makes the decision of grazing strategy $(\alpha, \hat{p})$ and insurance V, likewise according to modified Telser' Safety-First Rule. Formally, the decision problem is

$$\max_{(\alpha,\hat{p},V)} E(\frac{1}{T}\sum_{t=1}^{T} I_t) \quad \text{subject to } P((I_t) \le I_{min}) \le P_{tol}, \ \forall t = 1, \cdots, T \tag{7}$$

$$V \in \begin{cases} 1, & \text{closing of} \quad (i, p^*) \\ 0, & \text{not closing of} \quad (i, p^*) \end{cases},$$

subject to the ecological dynamics and a fair insurance (cf. Equations 3, 4).

2.6 Simulation

The simulation runs in yearly time steps. First, 100 years of vegetation dynamics without grazing were run. This time span was used to minimize the influence of

[2]Turvey (2001) assumes a rain threshold of $p^* = 0.95$ of long term mean. Skees *et al.* (2002, p.13) uses exemplarily $p^* = 0.67$ (corresponds to a strike of 200 mm rainfall with long term mean on 300 mm/y). One unit is equal to the value of one sheep.

initial conditions of vegetation R_0 on the dynamics. A spatial implicit model is constructed: A farm with sixty paddocks of equal size and habitat conditions is assumed. The statistics were calculated over 5000 simulation runs, with rainfall drawn from the underlying probability distribution.

2.7 Scenario analysis and sensitivity analysis

One purpose of the present study consists in analysing the role of the farmers' preferences on the choice of the grazing strategy. For that reason, the three parameters reflecting the farmers' preferences (time horizon T, minimal income I_{min} and tolerated risk level P_{tol}) were varied. The parameter values used can be found in Table 1. Similarly, the parameters which characterize the insurance (indemnity payment i, rain threshold p^*, below which insurance payment is granted) are indicated in Table 1. The table is completed to give an overview over the whole set of parameters. Income and indemnity payment are measured in sheep units. One unit insurance payoff equals the value of one sheep. One unit green biomass corresponds to the forage needed for one sheep per year.

Another part of the analysis is the investigation regarding how robust the results are assuming different ecological and climatic conditions. Ecological conditions are represented, among others, by the vegetation growth parameters w_{gr}, the growth rate of the sheep w_s, impact of grazing c and initial condition of the vegetation R_0. Climatic conditions are reflected by the parameters of the precipitation distribution $(E(p), \sigma(p))$. In a sensitivity analysis these parameters were varied (according to Table 1) to study their influence. With the help of latin hypercube sampling, 200 parameter sets are generated using the software SIMLAB 2.2 (Saltelli *et al.*, 2004). This method, by stratifying the input space into N desired strata, ensures that each input factor has all portions of its distribution represented by input values.

For each of the parameter sets, the corresponding values of the four following output variables have been calculated:

- expected value of average annual income $E(\frac{1}{T}\sum_{t=1}^{T} I_T)$ over time span T
- standard deviation of average annual income $\sigma(\frac{1}{T}\sum_{t=1}^{T} I_T)$ over time span T
- violation probability $P_{viol}(T) = P(I_T \leq I_{min})$ at time point T
- mean reserve biomass $E(R_T)$ at time point T

In a next step the Spearman's rank correlation coefficient was determined between these four output variables and the input parameters. This correlation coefficient is a measure of the correlation between data with monotone relationships and calculated using the ranks of the two considered samples.

Table 1: Parameter set used in the scenario analysis and in the sensitivity analysis (For the corresponding units it is referred to the explanations in the text)

	Parameters		Scenarios	Sensitivity analysis
Ecological conditions	Growth rate of green biomass	w_{gr}	1.2	0.5-2
	Growth rate of reserve biomass	w_{res}	0.2	-
	Strength of density dependence	d	0.000125	-
	Impact of grazing	c	0.5	0-1
	Initial reserve biomass	R_0	4000	0-6000
Climatic conditions	Mean annual rainfall	$E(p)$	1.2	0-3
	Standard deviation of annual rainfall	$\sigma(p)$	0.7	0-1
Preferences of the farmer	Time horizon	T	10, 40, 70	-
	Minimal income	I_{min}	200, 500	-
	Tolerated risk level	P_{tol}	0.02, 0.2	-
Farmers' choice				
Grazing strategy	Resting portion	α	0-1	0-1
	Rain threshold above which a part of the pasture is rested	$\hat{p}$	0-4	0-4
Insurance	Indemnity payment	i	0, 200	0-350
	Rain threshold below which indemnity payment	p^*	$0.75 \cdot E(p)$	$(0.5-1) \cdot E(p)$

3 Results

3.1 Preliminary results

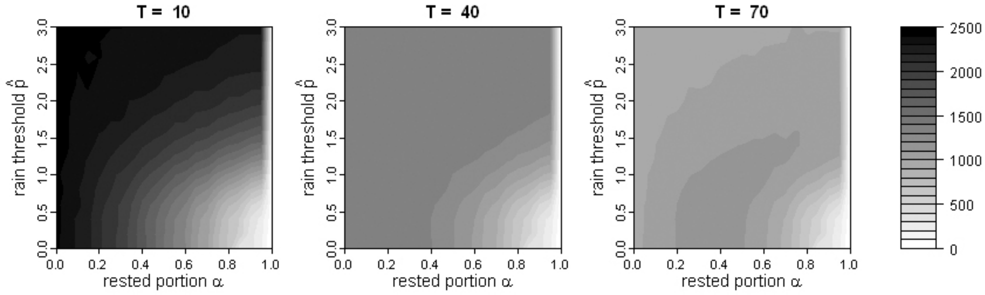
In order to understand the influence of insurance on farmer's choice of a grazing strategy, we conducted two prior steps: In the following paragraph the decision problem is left aside and the impact of the grazing strategies on expected value of average annual income and on expected value of average annual reserve biomass is shown. Furthermore the relationship between rainfall and income using a correlation analysis is presented. Thereby the case with and without insurance is contrasted. In the subsequent paragraph the role of the safety-first criterion without access to insurance on the chosen grazing strategy of the farmer is depicted.

3.1.1 Influence of grazing strategy and rainfall on income and reserve biomass

As a first step, we assume that the farmer's minimal required income is zero, i.e. that his objective simply is to maximize the expected income stream. For a large set of grazing strategies $(\alpha, \hat{p}) \in [0,1] \times [0,3)$, and different time horizons $T = 10$, 40 and 70 years the expected value of average annual income $E(\frac{1}{T}\sum_{t=1}^{T} I_t)$ was computed (Figure 3a). For the assumed ecological set up, the expected value of average annual income decreases over time. Thus, for different time horizons very different strategies $(\alpha, \hat{p})$ maximize $E(\frac{1}{T}\sum_{t=1}^{T} I_t)$: If the time horizon is short ($T = 10$), a grazing strategy which involves few resting periods (low portion of rested pasture α and high rain threshold $\hat{p}$) is optimal (Figure 3a left). For T=40 the result remains similar (Figure 3a middle). For a very long time horizon $T = 70$ the qualitative behaviour changes strongly (Figure 3a right). In that case, strategies with an intermediate level of resting are optimal. The reason is that high livestock numbers and, hence, a high income, are ensured in the long term only if reserve biomass production is maintained by applying some resting.

The results for the reserve biomass show, as expected, that the higher the resting (either comparably higher portion α, or resting above a lower rain threshold $\hat{p}$) the higher the expected value of average annual reserve biomass $E(\frac{1}{T}\sum_{t=1}^{T} R_t)$ (Figure 3b). There exist different strategies which lead to the same level of reserve biomass: For strategy $(\alpha_1, \hat{p}_1)$ and a rested portion $\alpha_2 \leq \alpha_1$, there can be found a rain threshold $\hat{p_2}$ such that $(\alpha_1, \hat{p}_1)$ and $(\alpha_2, \hat{p}_2)$ have the same expected value of average annual reserve biomass over time T (i.e. iso-expected reserve biomass lines). For the rain threshold the corresponding holds.

(a) Expected value of average annual income over T



(b) Expected value of average annual reserve biomass over T

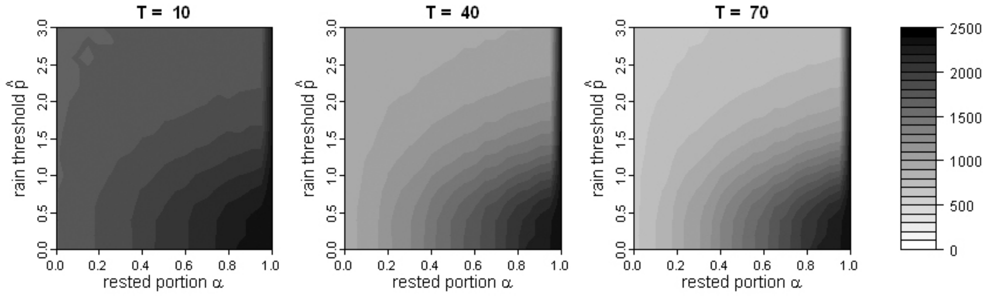


Figure 3: (a) Expected value of average annual income and (b) expected value of average annual reserve biomass over time horizon T and 5000 simulation runs for the whole set of grazing strategies. Farmers' time horizon T is varied $T = 10, 40, 70$.

Rainfall is a major driver of the system. Firstly it directly influences the amount of current green biomass and hence the current number of livestock on the farm, secondly it indirectly influences the dynamics of the stock of reserve biomass. Thirdly, it determines whether or not resting is carried out (the condition for resting is $p_t \geq \hat{p}$). Fourthly, in the cases involving insurance, rainfall determines whether an indemnity payment i of the insurance takes place or not.

The rain-index insurance functions only if income and rainfall are positively correlated. We therefore determined the correlation between the income I_t in year t and the current rainfall p_t, depending on the grazing strategy $(\alpha, \hat{p})$ and whether or not the farmer has bought a particular insurance contract, $(i = 200, p^* = 0.75)$. As shown in Figure 4 the correlation between rainfall and income is lower with insurance than without: this is because, whatever the income without insurance is, a certain amount of income is negatively correlated to rainfall due to the rain-index insurance (given the specified contract).

But also the applied grazing strategy has a large influence on the correlation between income and rainfall: Without any resting ($\alpha = 0$) and without insurance, there exists a strong correlation. Over time, the correlation between income and rainfall decreases strongly in the case with insurance. The reason is that the payoff

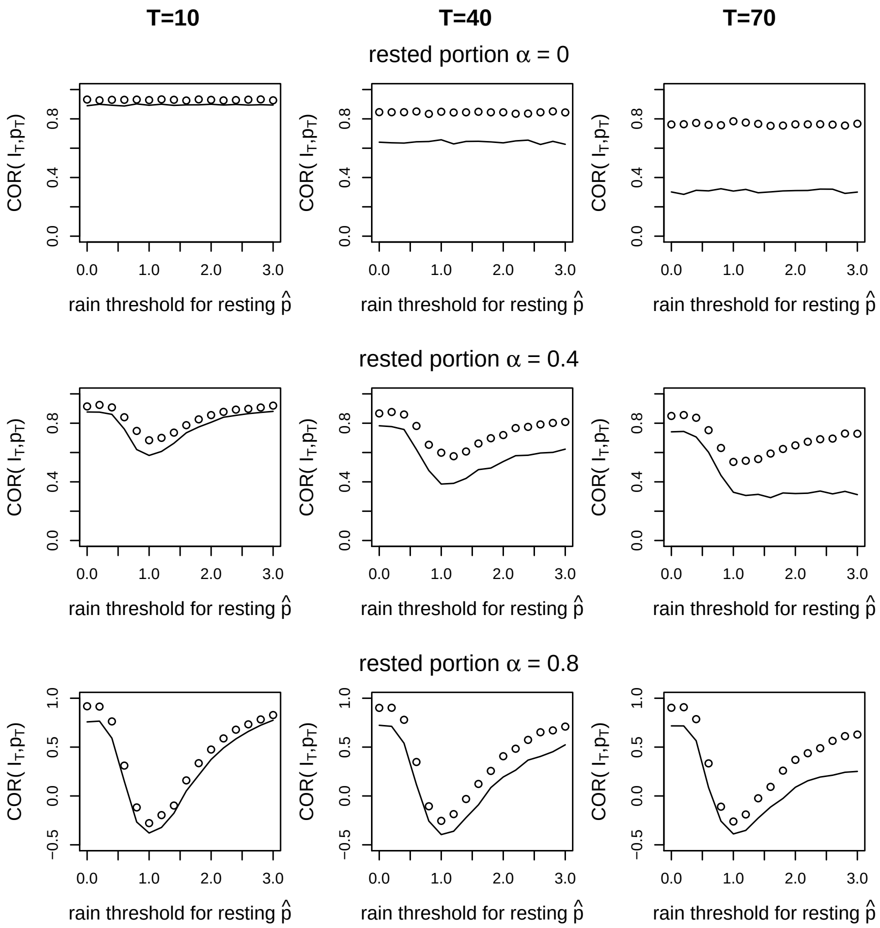


Figure 4: Spearman-correlation coefficient of income I_T and precipitation p_T at time $T = 10, 40, 70$, (1) without insurance (dots) and (2) with insurance ($i = 200, p^* = 0.75$) (line) for different grazing strategies $(\alpha, \hat{p})$.

i and the premium b of the insurance remain constant over time, while the income gained from livestock is decreasing. Hence i and b have an increasing influence on income over time.

The higher the rested portion α, the more the rain threshold $\hat{p}$ influences the correlation between current rainfall p_t and income I_t: If resting is carried out in each year ($\hat{p}$ small) or almost never (high $\hat{p}$) the correlation of I_t and p_t is very high. The case of a very high rain threshold is equal to the case without resting at all. In the case of a very low rain threshold, resting is applied in (almost) every year. For the remaining paddocks, livestock has to be adapted to forage and, hence to rainfall, just as in the case without any resting. For intermediate thresholds the correlation of income and rainfall is low and can, for excessively high proportions of resting, become even negative. The minimal correlation is reached at approximately $\hat{p} = 1$ (for comparison: the assumed median of the rainfall distribution lies at 0.85). The intuition behind this result is as follows: If current rainfall p_t is above the threshold $\hat{p}$, a very large part of the pasture is rested, leading to a very small number of sheep kept on the farm and, hence, to very low income. As a consequence, if the part rested is excessively high, the number of livestock in rainy years with resting is even lower than in dry years, where no resting is carried out.

Concluding, the grazing strategy is of high influence on the correlation between income I_t and rainfall p_t at time t. Thus, the choice of an appropriate grazing strategy can effectively reduce income variability.

3.1.2 What does safety-first criterion imply?

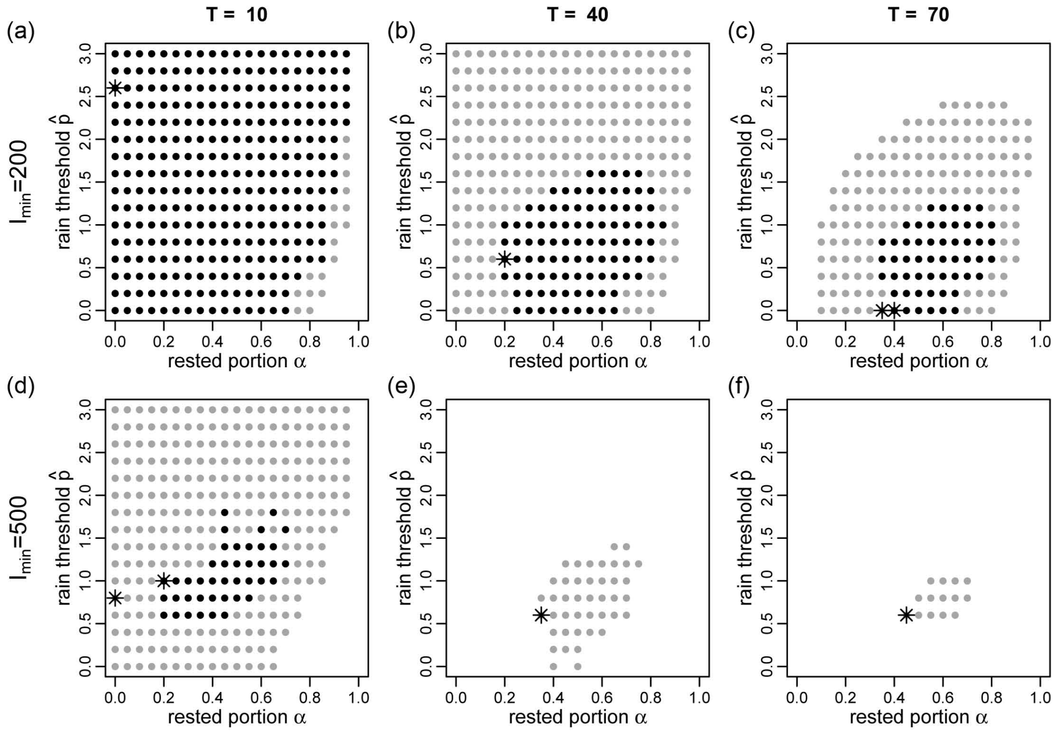


Figure 5: Admissible strategies without insurance for tolerated risk level $P_{tol} = 0.02$ (black), 0.2 (grey) and the corresponding optimal strategies (*) applying the safety-first rule. The minimal income takes the values $I_{min} = 200$ (Figure a, b, c) and $I_{min} = 500$ (Figure d, e, f) and the time horizons are chosen to be $T = 10, 40, 70$.

Three parameters characterize the preferences of the farmer: time horizon T, minimal income I_{min} and tolerated risk level P_{tol}. In the following we show how the optimal strategy depends on the different preference parameters. We therefore considered two values of the minimal income $I_{min} = 200$ and $I_{min} = 500$, two values for the tolerated risk level $P_{tol} = 0.02$ and $P_{tol} = 0.2$ and three values for the time horizon $T = 10$, $T = 40$ and $T = 70$. For each set of parameters, the set of admissible strategies and the optimal strategy were calculated.

For the short time horizon $T = 10$, and comparably low minimal income $I_{min} = 200$, almost all strategies are admissible, independent of P_{tol}. The reason is that this low minimal income level seldom falls short, expect when applying strategies with an extremely high part of resting (Figure 5a right lower corner). The resulting optimal strategy ($\alpha = 0, \hat{p} = 2.8$) includes no resting.

Assuming high minimal income ($I_{min} = 500$) and small tolerated risk level ($P_{tol} = 0.02$), strategies without any resting are not admissible (Figure 5d). The optimal strategy ($\alpha = 0.2, \hat{p} = 1$) includes a small part of resting. Hence, farmers with higher minimal income I_{min} rest more, ceteris paribus.

For longer time horizons the range of admissible strategies decreases ceteris paribus. If the minimal income is high ($I_{min} = 500$) and the tolerated risk level is low ($P_{tol} = 0.02$), no admissible strategy exists at all. Also for a lower minimal income and a higher tolerated risk level, only strategies including resting are admissible. Without resting the vegetation is in such bad condition that not enough livestock can be kept on the farm in order to ensure the minimal income I_{min}. Hence, for long-planning farmers, resting is an important part of the management strategy. But the frequency of resting depends on the minimal income and the tolerated risk level: A farmer who seeks to reach a comparably high minimal income $I_{min} = 500$ will carry out resting only in rainy years ($\hat{p} > 0.6$) (Figure 5f). The reason is that in order to generate enough income in dry years, resting during these dry years is not possible.

3.2 Does insurance lead to a less sustainable grazing strategy?

3.2.1 One specific insurance contract

In this paragraph we assume that the farmer decides, apart from the grazing strategy, whether he signs a specific insurance contract ($i = 200, p^* = 0.75$) or not (decision problem Equation 7). The decision is made at $t = 1$ and if the farmer has signed the insurance contract, he will have to comply until the end of the time horizon. He will do so, if under the optimal grazing strategy in the case with insurance the expected value of average annual income is higher than under the optimal grazing strategy without insurance.

Given a fixed grazing strategy, the insurance, assumed to be actuarially fair, does not change the expected value of average annual income. By affecting income deviations downwards, insurance may influence the range of admissible strategies. The analysis has shown that the range of admissible strategies extends with insur-

Table 2: Results of the Wilcox-Test to investigate whether insurance ($i = 200, p^* = 0.75$) leads to optimal strategies with significantly superior expected value of average annual income over time T compared to no insurance (P-level=0.05). Minimal income I_{min}, tolerated risk level P_{tol} and time horizon T of the farmer are varied. "1*" denotes significant superiority with insurance,"0" no significant difference between with and without insurance, "-" no grazing strategy is admissible.

		$P_{tol} = 0.02$	$P_{tol} = 0.2$
$T = 10$	$I_{min} = 0$	0	0
	$I_{min} = 200$	0	0
	$I_{min} = 500$	1*	0
$T = 40$	$I_{min} = 0$	0	0
	$I_{min} = 200$	-	0
	$I_{min} = 500$	-	1*
$T = 70$	$I_{min} = 0$	0	0
	$I_{min} = 200$	-	0
	$I_{min} = 500$	-	0

ance. Only in the case of extremely high premiums in relation to income there exist strategies which are admissible without, but not with insurance. In this case, the high insurance premium may involve shortfalls of the minimal income in wet years.

Ruling out this unrealistic case, insurance can only increase the expected value of average annual income. The grazing strategy is altered in the case with insurance, if a strategy with higher expected value of average annual income becomes newly admissible.

In Table 2 for different preference parameters it is contrasted whether insurance leads to distinct optimal strategies with significantly higher/lower expected value of average annual income or not. Only for two preferences, insurance leads to significantly higher expected value of average annual income over the time span T.

If the level of minimal income is high ($I_{min} = 500$) and the time horizon is short or middle. We shall discuss the reasons for this result in some detail. The simulations for $I_{min} = 500$ are shown in Figure 6.

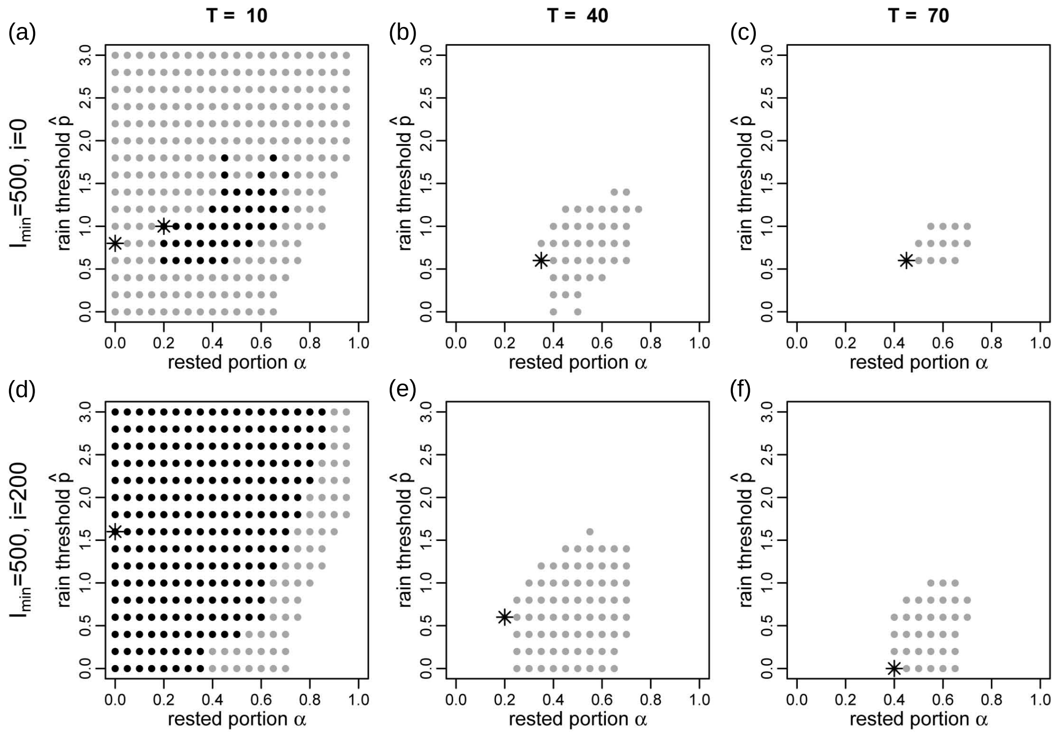


Figure 6: Admissible strategies for $I_{min} = 500$, tolerated risk level $P_{tol} = 0.02$ (black), 0.2 (grey) and the corresponding optimal strategies (*) without insurance $i = 0$ (Figure a,b,c) and with insurance ($i = 200, p^* = 0.75$) (Figure d,e,f) and three different time horizons $T = 10, 40, 70$ applying the safety-first rule.

For a short time horizon ($T = 10$) and low tolerated risk level $P_{tol} = 0.02$, the signing of the insurance contract ($i = 200, p^* = 0.75$) leads to significantly higher income (cf. Table 2, 2200 versus 2400 units expected value of average annual income). In the case with insurance the optimal strategy implies no resting ($\alpha = 0$) compared to the case without insurance ($\alpha = 0.2, \hat{p} = 1$) (Figure 6a,d). Hence in this case, access to insurance leads to less resting.

The reason is that resting in rainy years is no longer necessary to maintain a certain level of livestock numbers and, hence, income in dry years, since the indemnity payment of the insurance is available during these years. In other words, the target to reach the minimal income $I_{min} = 500$ can be fulfilled without resting. For medium time horizons ($T = 40$) the tendency is analogous: The insurance leads to significantly higher expected value of average annual income and less resting is optimal compared to the case without insurance.

In the long time horizon ($T = 70$), as we have seen in Table 2, insurance does not lead to an increase in expected value of average annual income. The detailed analysis shows that only strategies with a medium level of resting are admissible (Figure 6f). Resting remains essential in the case with access to insurance.

For an explanation consider an exemplary simulation run (Figure 7): Given a strategy without resting ($\alpha = 0, \hat{p} = 0.8$) the income flow in the case with (payoff $i = 200$) and without insurance is mapped. The minimal income required by the farmer I_{min} is assumed to be 500. The white bars indicate the years where rain does not reach the threshold $0.75 \cdot E(p)$ and hence the insurance pays out, if a contract is settled. Especially in these low rainfall years, the minimal income level I_{min} is violated without insurance (Figure 7b). However with insurance the level I_{min} is reached in the years where the insurance pays out, but not in all remaining years, when rainfall is above the rain threshold (for instance year 41; cf. Figure 7c). Two aspects play a role. Firstly the income in rainy years is reduced by the insurance premium. Secondly, the condition of the pasture becomes so bad due to little resting, that even in years with sufficient rainfall the minimal income I_{min} is not reached. For comparison, a strategy with a high portion of resting ($\alpha = 0.4, \hat{p} = 1.5$) is mapped, assuming the same rainfall scenario (Figure 7d). Applying this strategy, where resting in rainy years is granted, no insurance is necessary to reach $I_{min} = 500$ with a tolerated risk level of $P_{tol} = 0.2$. Summarizing, resting is important to reach I_{min} independent of the insurance payoff, if the farmer has a long time horizon.

Getting back to the expected value of average annual income for time horizon $T = 70$ (Figure 6c,f): Surprisingly, with insurance the range of admissible strategies is increased by strategies which rest even more - not only in rainy years but in each year ($\hat{p} = 0$). The reason is the following: Without insurance the farmer has to care for sufficient livestock on the farm in dry years. Hence in dry years resting is not possible in order to reach the minimal income. With insurance the income is supported in dry years by the insurance payment. Hence "resting in each year" becomes admissible. Over the long run, and for a zero discount rate, the strategy with resting in every year generates the highest expected value of average annual income, because the reserve biomass is least degraded and, hence, income can be maintained at a relatively high level.

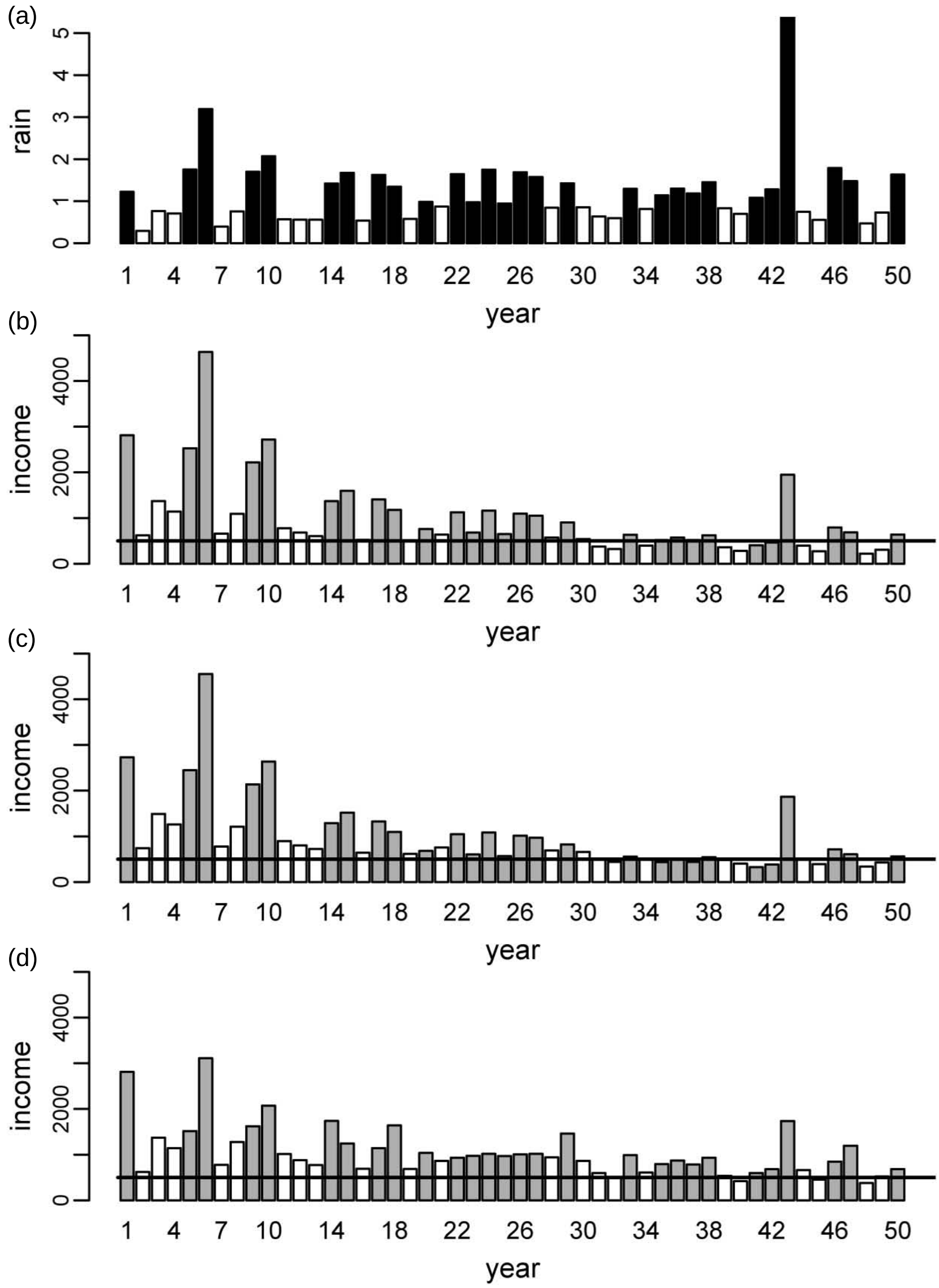


Figure 7: a) Rainfall, b) Income applying strategy ($\alpha = 0, \hat{p} = 1.5$) without insurance, c) Income applying strategy ($\alpha = 0, \hat{p} = 1.5$) with insurance (payoff $i = 200$), d) Income applying strategy ($\alpha = 0.4, \hat{p} = 1.5$) without insurance, for a period of 50 years (α - rested portion, $\hat{p}$ - rain threshold above which resting is carried out).

3.2.2 Choice between different insurance contracts

Until now we supposed that the farmer has only the choice of deciding whether he signs one specified insurance contract or not. In the following it is depicted whether the results change, if the farmer can choose between nine different insurance contracts. The contracts result from all possible combinations of rain threshold p^* and indemnity payment i:

- rain threshold above which payoff $p^* = 0.55, 0.75, 0.95$
- indemnity payment $i = 100, 200, 300$ sheep units

From all insurance contracts that contract was determined, which involves the (admissible) grazing strategy with the highest expected value of average annual income.

Similar to the analysis above (Table 2), it was tested whether for this contract and the associated grazing strategy the expected value of average annual income was higher compared to the case without insurance. The analysis was carried out for the same preference sets as in Table 2.

The results depicted the same optimal strategies as in the case where only one insurance contract was available: Insurance leads to significantly higher expected value of average annual income over time horizon T for the same preferences parameters: If the level of minimal income is high ($I_{min} = 500$) and the time horizon is short or middle.

The optimal insurance contract for the first case ($T = 10, I_{min} = 500, P_{tol} = 0.02$) is a payoff of $i = 200$ when rainfall is 55% of the long-term rainfall mean ($p^* = 0.55$). For the second case ($T = 40, I_{min} = 500, P_{tol} = 0.2$), the optimal contract is, as before, ($i = 200, p^* = 0.75$).

Thus, the availability of different insurance contracts does not substantially alter the previously found results. These indicated that only for short or middle time horizons, high minimal incomes and low tolerated risk levels, insurance leads to significantly higher income than without insurance. In these cases, the associated grazing strategies imply less resting.

3.2.3 How robust are the results for different ecological and climatic settings?

Table 3: Spearman Rank Correlation Coefficient for four target variables and six ecological and climatic parameters, time horizon chosen is 70 years, significance level * P=0.05, *** P=0.001

	$E(\frac{1}{T}\sum_{t=1}^{T} I_t)$	$\sigma(\frac{1}{T}\sum_{t=1}^{T} I_t)$	$P_{viol}(T)$	$E(R_T)$
w_{gr}	0.367***	0.349***	-0.324***	0.289***
$E(p)$	0.751***	0.377***	-0.600***	0.745***
$\sigma(p)$	-0.037	0.337***	0.016	0.038
c	0.064	0.122	0.155*	-0.170*
R_0	0.092	0.065	-0.096	0.077

The Spearman Rank Correlation Coefficient indicates a highly significant positive impact of mean annual precipitation $E(p)$ and growth rate of green biomass w_{gr} on expected value of average annual income $E(\frac{1}{T}\sum_{t=1}^{T} I_t)$ over time span T and mean reserve biomass $E(R_T)$ at time point T (Table 3). These parameters are, in addition, significantly negatively correlated to the probability $P_{viol}(T)$ with which the safety level I_{min} is violated. The parameter indicating the impact of grazing c is significantly correlated to mean reserve biomass $E(R_T)$ as well as to the expected value of average annual income $E(\frac{1}{T}\sum_{t=1}^{T} I_t)$. Here, only the results for time horizon $T = 70$ years are presented. An analysis not indicated here reveals that, qualitatively, the same holds for other time horizons.

The previous results - access to insurances leads to ecologically detrimental grazing strategies assuming a short term thinking farmer - do not hold if the regeneration rate of the vegetation is high (high mean annual precipitation $E(p)$ or high growth rate of green biomass w_{gr}). This corresponds to a result in Müller *et al.* (2007), where it was shown that, assuming regeneration rate of the vegetation to be high enough, resting is not necessary to maintain the pasture in a good condition. Hence, in this case access to insurance does not negatively influence the vegetation. However, semi-arid regions are just characterised by low mean annual precipitation $E(p)$ and low growth rate of green biomass w_{gr}.

Different initial conditions (indicated by R_0) have a small effect on the results, apart from the case where the vegetation condition is so bad that livestock farming is not possible. The standard deviation of rainfall $\sigma(p)$ influences significantly the standard deviation $\sigma(\frac{1}{T}\sum_{t=1}^{T} I_t)$ but not the expected value of average annual income $E(\frac{1}{T}\sum_{t=1}^{T} I_t)$.

4 Discussion

Before we discuss the main topic of this study - the influence of access to insurances on the grazing strategy - let us first look at the assumed decision criterion of the farmer, the safety-first rule.

The decision criterion applied is a safety-first rule: the primary goal being to reach a certain minimal income in each year. This safety-first rule can be interpreted as the goal to ensuring the economic viability of the managed system. Especially for small-scale farmers in developing countries this criterion seems to be a more adequate description of decision making than pure expected utility maximization of income. Numerous studies in agricultural economics in which the criteria is used support this (including Shively, 1997, 2000; Van Kooten *et al.*, 1997; Qiu *et al.*, 2001).

In the case without access to a rain-index insurance, our results show that the farmer's optimal strategy is highly dependent on his time horizon. Farmers with a short time horizon, a low minimal income, or a high tolerated risk level do not apply resting at all. The intuition for this result is that, since risk and the long term impact of grazing on the pasture do not matter, they apply a strategy wherein the pasture is fully stocked with livestock, and thus the highest expected value of average annual income is generated. On the other hand, farmers with a short time horizon, but who require a high minimal income and have a low tolerated risk level need to rest in rainy years in order to generate forage reserves for the livestock in dry years.

For a long-term-thinking farmer, resting a part of the pasture is fundamental, since a good long-term condition of the pasture is crucial for maintaining productivity and hence sufficient income under the assumed ecological set-up. Hence, in the long run, a strategy with resting allows a higher expected yield, and resting will be applied independently of the safety first rule. However, the parameters of the safety first criterion have an effect thereon, in which years rest periods are granted. If the farmer has a high minimal income and a low tolerated risk level to fall short this target, resting is not carried out in each year, but only in years with sufficient precipitation. Otherwise, if resting would be carried out also in dry years, the livestock numbers need to be reduced during these years for two reasons: because of the lack of rain and because of the granting of rests for a part of the pasture. Consequently, the minimal income level cannot be reached. The other way around, farmers who require a low minimal income or have a high tolerated risk level do not have to be cautious for the choice of the year to rest. This result holds independent of the time horizon.

The principal focus of the present study was to investigate whether the availability of a rain-index-based insurance influences a farmer's strategy choice towards less sustainable strategies. Our analysis, which considered a fair insurance contract without costs, confirmed this hypothesis: Insurance leads to less sustainable strategies - but only for farmers with short time horizons. Farmers with short time horizons but who require a high minimal income and have a low tolerated risk level can cope with dry years by using the indemnity payment of the insurance. Hence, resting during the other rainy years in order to generate forage reserves is not necessary, when compared to the case without insurance. However, the hypothesis proves to be false when a long term thinking farmer is assumed. Given the underlying ecological conditions, resting in rainy years leads to a higher expected value of average annual income in the long run with or without insurance, independently of the specification of the farmer's safety first rule. The reason is that resting is necessary to maintain the productivity of the pasture in the long run.

A counter-intuitive result is that for a farmer with a long time horizon, insurance can lead to increased resting: Not only in rainy years, but in dry years as well. It results from the following effect: In dry years the minimal income level is reached despite resting a part of the pasture, since the indemnity payment is available for the farmer. This enables the possibility of even more resting, maintaining a higher productivity of the pasture in the very long run.

We have shown that a grazing strategy with resting in rainy years generates benefits in two respects: On the one hand, the correlation between rainfall and income is reduced, i.e. income risk is reduced. On the other hand, resting enables to maintain the productivity of the pasture in the long run. Thus, it may be seen as an investment, which in return generates a higher future income. A rain-index insurance can take over only the first function, but not the second function. Hence, long-term thinking farmers can apply a strategy with resting, in order to maintain the pasture's productivity, and an index-based rain insurance, in order to overcome short-run droughts.

One conclusion of the present study is the following: The incentives for farmers to change their strategies under insurance availability has to be kept in mind, if policy instruments for reducing income risk, such as insurance, are going to be designed. In order to understand the impact of governmental policies offering risk management strategies on land use, ecological-economic models which explicitly include the relevant ecological and economic aspects and feedback dynamics, such as the study presented here does, may offer an adequate approach.

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