Pitfalls and potential of institutional change

Müller, Birgit; Quaas, Martin; Frank, Karin; Baumgärtner, Stefan

Publication date:
2009

Document Version
Publisher's PDF, also known as Version of record

WORKING PAPER

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

by
Birgit Müller, Martin Quaas, Karin Frank and Stefan Baumgärtner

University of Lüneburg
Working Paper Series in Economics

No. 149

November 2009

www.leuphana.de/vwl/papers

ISSN 1860 - 5508

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

Birgit Müller,[a,*] Martin Quaas,[b] Karin Frank[a] and Stefan Baumgärtner[c]

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

[b] Department of Economics, Christian-Albrechts University of Kiel, Germany

[c] Department of Sustainability Sciences, Leuphana University of Lüneburg, Germany

October 2009

Abstract: Rain-index insurance is strongly advocated in many parts of the developing world to help farmers to cope with climatic risk that prevail 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, a rain-index insurance with a low to medium strike level enhances the farmer's well-being while not impairing the sustainability of rangeland management.

Keywords: ecological-economic modeling, weather-index insurance, Namibia, grazing management, risk, sustainability, weather-based derivatives

JEL-Classification: D81, G22, Q14, Q56, Q57

* Corresponding author: UFZ,Helmholtz Centre for Environmental Research - UFZ, Department of Ecological Modelling, P.O. Box 500135, 04301 Leipzig, Germany. Email: birgit.mueller@ufz.de, Fax: +49-341-235-1473.

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 by subsistence 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 lead to land degradation and desertification (Westoby et al. 1989, Sullivan and Rohde 2002). According to UNCCD estimates, 41 percent of the earth is vulnerable to land degradation, and drylands are expected to increase by an additional 11 percent by 2080 in developing countries (UNCCD 2009). 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 some 42 billion US dollars per year (UNCCD 2008).

Against this background, rain-index insurance has been advocated prominently as an effective and economically sensible means to 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, WorldBank 2005, United Nations 2007, Barnett et al. 2008, Berg 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).

A rain-index insurance means that a certain 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, a rain-index insurance actually functions as an insurance 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 farmer's behavior, difficult to manipulate, transparent, and easy to monitor (Skees and Barnett 1999, Miranda and Vedenov 2001).

However, there is evidence that access of farmers to insurance may have ecologically detrimental consequences. 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), with more soil erosion (Wu 1999), or with reduced biodiversity conservation efforts (Baumgärtner 2007, Baumgärtner and Quaas 2009a, Quaas and Baumgärtner 2008). 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).

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 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; (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 that sake, 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 remainder of the paper is organized as follows. In Section 2, we develop 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 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. To this model, we add here a stylized description of rain-index insurance. The basic structure of the model is presented in Figure 1.

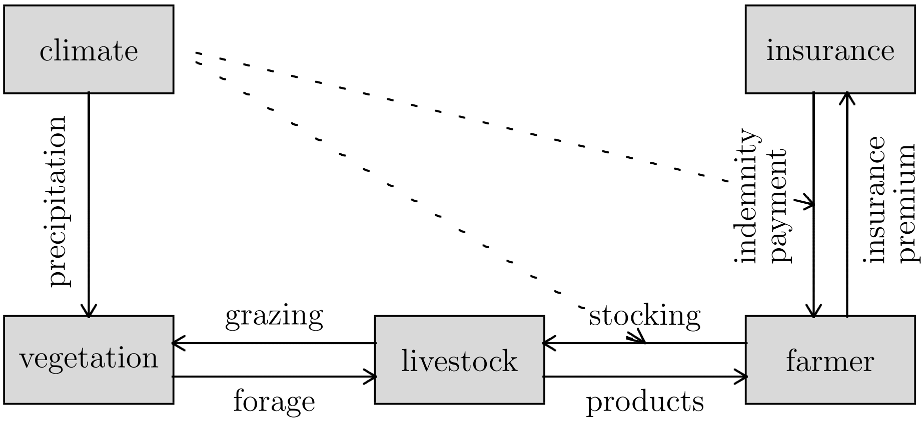

Figure 1: Schematic representation of the model structure.

Ecological sub-model: vegetation dynamics

The vegetation dynamics is mainly driven by two factors: precipitation and grazing. Precipitation is measured in units of effective rain events per year, that is the number of rain events that are effective in triggering plant growth. For easier handling a continuous scale is assumed. Precipitation p is modeled as an independently and identically distributed random variable, following a log-normal distribution. This is a right-skewed distribution, where events with low rainfall are frequent, but eventually high-rainfall-events occur, which is adequate for semi-arid areas (Sandford 1982). The probability density function is

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

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. The green biomass G_t in time step t is given by

$$G_t = w_G p_t R_t \quad \text{for} \quad t = 1, \dots, T. \tag{2}$$

where w_G is a conversion parameter, indicating the extent to which the green biomass G_t responds to reserve biomass R_t and current plant-available water p_t. (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:

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

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. The reserve biomass increases by photosynthesis in proportion to the amount of effective green biomass with a proportionality factor w_R. A density dependence in reserve biomass growth is captured by the factors containing the parameter d. The higher d, 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. For this sake, we measure the number of livestock in terms of green biomass available as forage. Full stocking, $S_t = G_t$, means that all available forage is used. In this case the growth of reserve biomass by photosynthesis is reduced by a factor $1 - c$ with $0 \leq c \leq 1$. A value of c near 0 (1) indicates a low (high) impact of grazing on the dynamics of the reserve biomass. 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.

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

Grazing management is assumed to follow a "resting in rainy years"-strategy, where the 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. This 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 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 in percent 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 $p_t \leq p^{\mathrm{gr}}\, E(p_t)$. 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 that the farmer chooses a grazing strategy before first grazing (i.e. in year $t = 0$) and applies it in every subsequent year. In order to focus on environmental constraints and risks – rather than on market constraints and risks – we assume that the livestock numbers can be adapted to the desired level at no costs.

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 $(1, p^{\mathrm{ins}})$ with a payoff of 1 if precipitation falls below the "strike", a fixed annual rain level p^{ins}, which is measured in percent of the long-term mean annual rainfall $E(p_t)$.[2] 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^{ins}. 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, $p_t \leq p^{\mathrm{ins}}\, E(p_t)$, and $-b\, i < 0$ if actual rainfall is above, $p_t > p^{\mathrm{ins}}\, E(p_t)$. We assume an actuarially fair insurance. That means the annual unit premium b is equal to the expected indemnity payoff of the insurance in every year.

The farmer's annual income from livestock grazing is given by the revenues of selling livestock products such as meat, milk, 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. Including the rain-index insurance, the farmer's 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, if $p^{\mathrm{ins}} < p^{\mathrm{gr}}$, income is

$$I_t = \left\{ \begin{array}{rl} G_t & \text{if} \quad p_t \leq p^{\mathrm{gr}}\, E(p_t) \\ (1 - \alpha/100\%)\, G_t & \text{if} \quad p_t > p^{\mathrm{gr}}\, E(p_t) \end{array} \right\} + \left\{ \begin{array}{ll} -b + i & \text{if } p_t \leq p^{\mathrm{ins}}\, E(p_t) \\ -b & \text{if } p_t > p^{\mathrm{ins}}\, E(p_t) \end{array} \right. \qquad (4)$$

The farmer's preferences over the uncertain stream of present and future income are described by the following 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.

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. Instead, 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, $\bar{I}$, and reserve biomass, $\bar{R}$, 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:[3]

$$\mathrm{Prob}(I_T \geq \bar{I}) \geq \bar{q}_I \tag{6}$$

$$\mathrm{Prob}(R_T \geq \bar{R}) \geq \bar{q}_R \,. \tag{7}$$

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 $\bar{q}_I$ and $\bar{q}_R$.

Calibration and simulation method

The ecological and climatic parameters were calibrated according to the ecological model in Müller et al. (2007) where also a sensitivity analysis was performed to analyze the qualitative behavior of the model. The parameters for the discount rate and the degree of relative risk-aversion are chosen according to the results from a survey with 360 respondents among approximately 2.200 Namibian livestock farmers and experiments we conducted with 39 Namibian farmers (Olbrich et al. 2009). Table 1 gives an overview of the parameter values used in the simulations. 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.

Table 1: Parameter values used in the analysis.

	Parameters		Values
Ecological conditions	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
Climatic conditions	Mean annual rainfall	$E(p_t)$	1.2
	Standard deviation of annual rainfall	$\sigma(p_t)$	0.7
Farmer's preferences	Risk aversion	θ	2.0
	Time horizon	T	30
	Discount rate	δ	0.25

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

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 way that it reduces income variability.

Figure 2 shows the expected income at time T, $E(I_T)$, for many different grazing management strategies $(\alpha, p^{\mathrm{gr}}) \in [0, 100\%] \times [0, 240\%]$ and two time horizons ($T = 1$ and 70 years). 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 2a). For a very long time horizon ($T = 70$), the qualitative behavior changes strongly (Figure 2b). 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 2d). 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 2e and f. For both $T = 1$ and $T = 70$ the lowest income risk results from medium levels

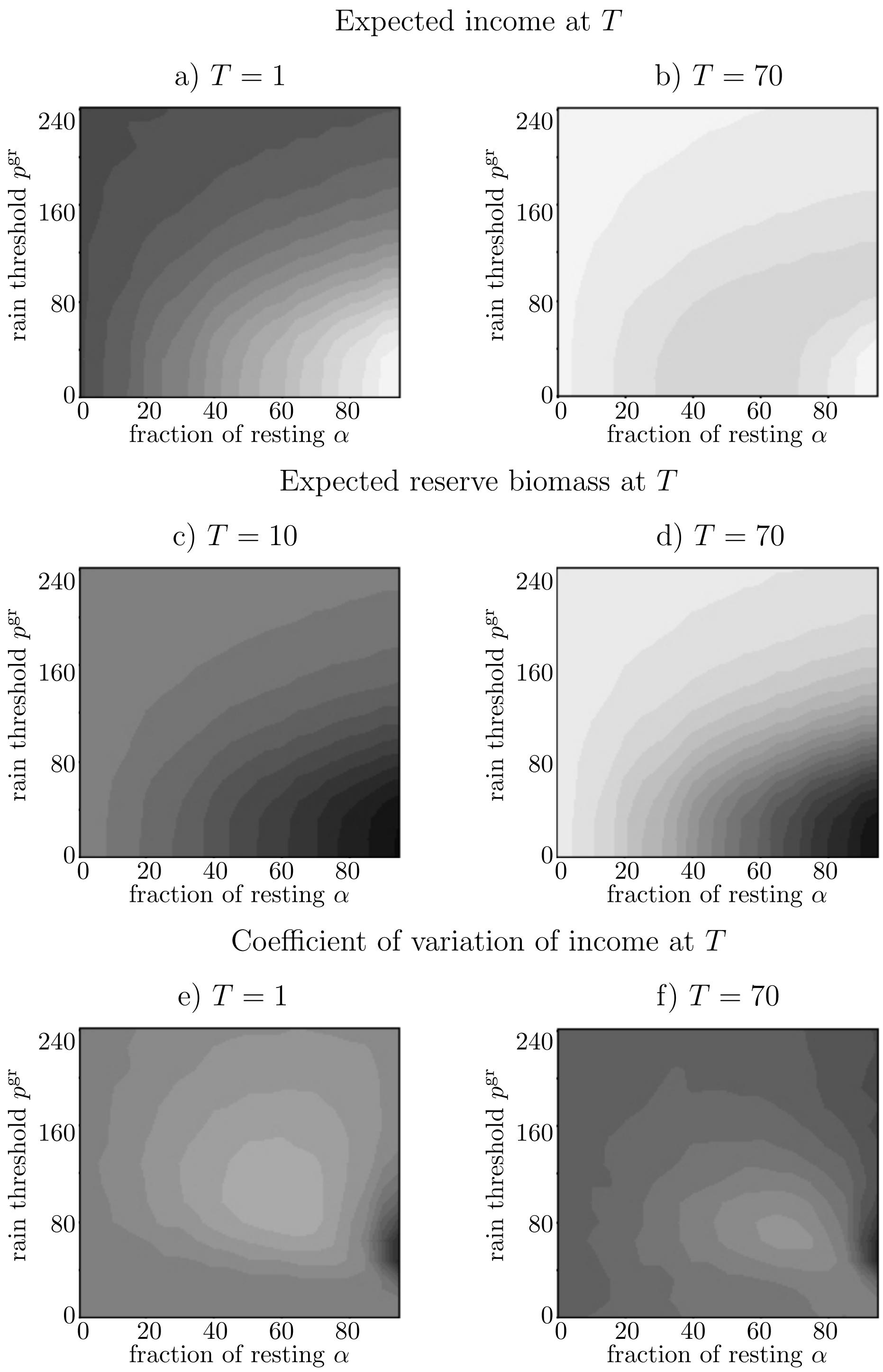

Figure 2: Expected income $E(I_T)$ (a,b), expected reserve biomass $E(R_T)$ (c,d) and coefficient of variation of income $CV(I_T) = Sd(I_T)/E(I_T)$ (e,f) at times $T = 1$ (for reserve biomass $T = 10$) and $T = 70$, for different strategies characterized by the fraction of resting α (in percent) and 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 $CV(I_T)$.

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 ($p^{\mathrm{gr}} < 50\%$). 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.

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

In the following, we study the effects of introducing a rain-index insurance in the following way: 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 $(\alpha, p^{\mathrm{gr}})$. 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 graph) shows the optimal amount of insurance 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 a rain-index insurance improves the farmer's well-being. The figure also shows that the optimal strike level from the farmer's perspective is at about 50% of the long-term mean annual rainfall.

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} affect 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

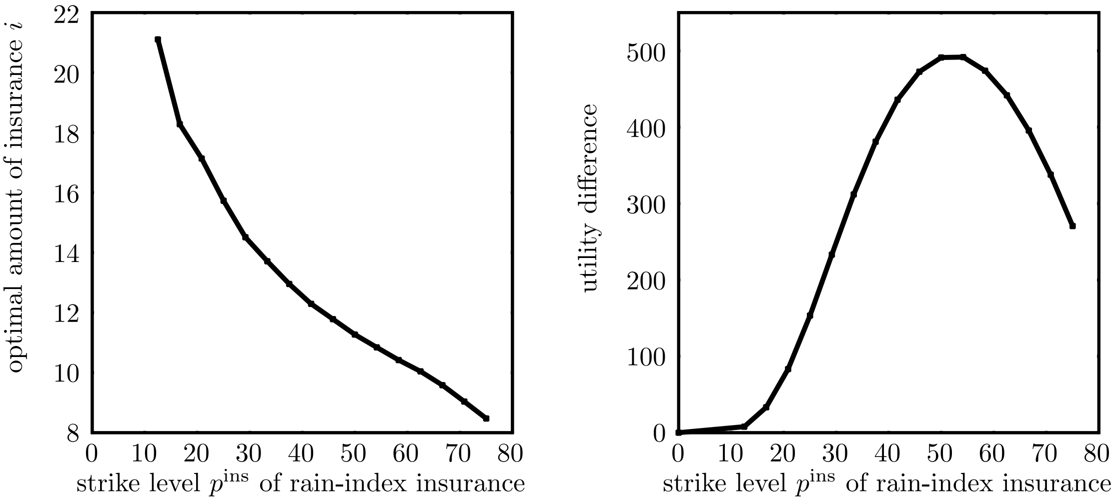

Figure 3: Optimal amount i of rain-index insurance (left), measured in percent of the maximal average income, i.e. the average income that could be obtained from a pristine pasture with full stocking, and the difference between the present value of utility (V) with and without rain-index insurance (right)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

strategy p^{gr} with insurance. The dotted lines show the corresponding values without insurance.

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-

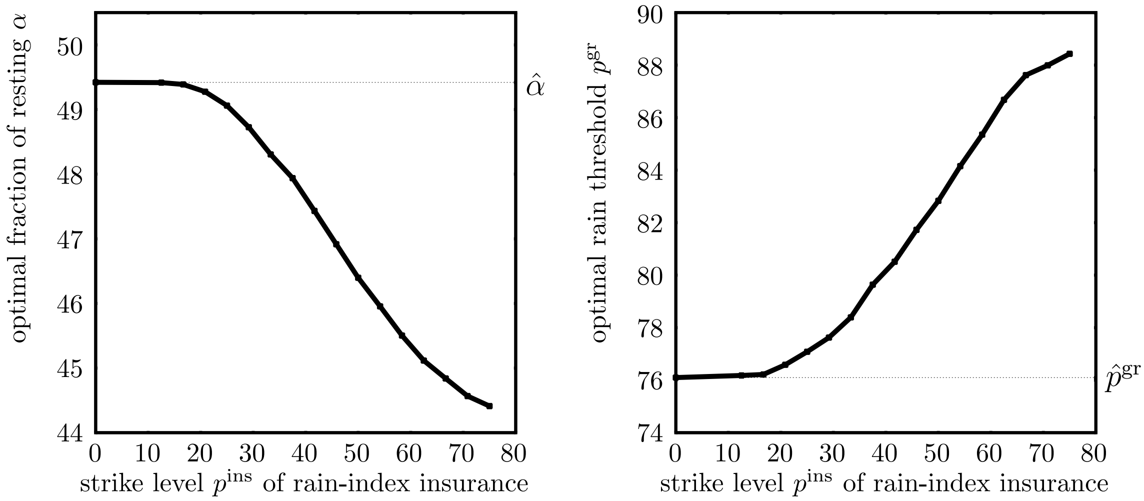

Figure 4: Optimal fraction α (in percent) of resting for different strike levels p^{ins} of the rain-index insurance (left), where $\hat{\alpha}$ denotes the optimal fraction of resting without rain-index insurance, and the optimal rain threshold p^{gr} of the grazing management strategy (right), measured in percent of mean rainfall, where $\hat{p}^{\text{gr}}$ denotes the optimal rain threshold without rain-index insurance.

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.

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

Consequently, the sustainability of grazing management also depends on the type of rain-index insurance available to the farmer. Figure 5 shows our results concerning the sustainability of the optimal grazing management strategy for different strike levels of the rain-index insurance. What is shown in the figure are the probabilities that defined 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 25% 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 25% 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 20% (30%) level.

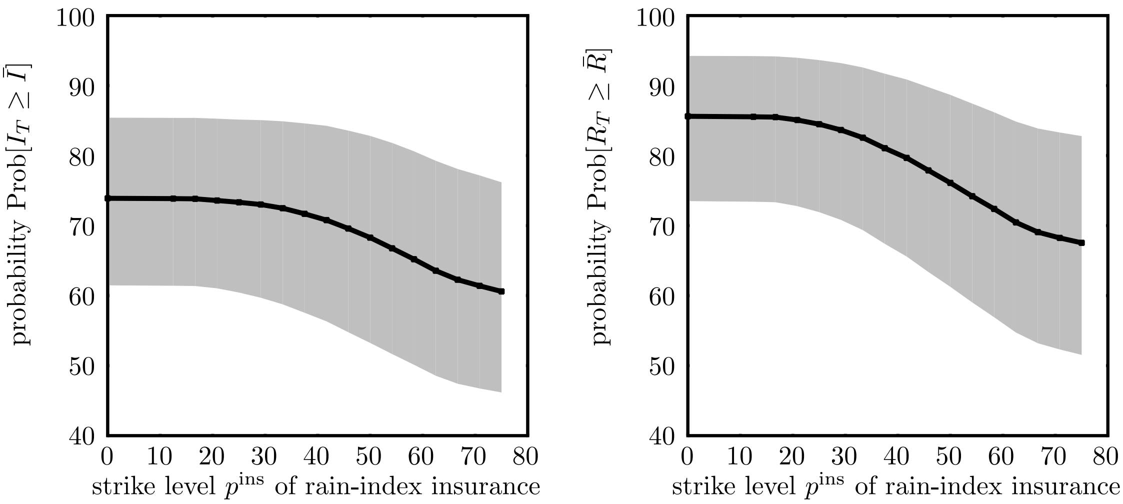

Figure 5: Sustainability of rangeland management as a function of the rain index insurance's strike level. Sustainability is measured as the probability (in percent) that 25% of maximal average income (left) and 25% of maximal reserve biomass (right) are reached at the end of the time horizon, $T = 70$ years. The upper (lower) bounds of the shaded areas depict the probabilities for the respective thresholds at 20% (30%) level.

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.

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 the well-adapted and 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. We have found three major results:

First, the introduction of a rain-index insurance improves the farmers' welfare. The individual farmer's benefit of a rain-index insurance is highest for an intermediate strike level of about 50% of long-term mean rainfall according to our simulation results.

Second, natural insurance by a conservative grazing management strategy and financial rain-index insurance are substitutes for the farmers' risk management. As a result, the introduction of a 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 between 30 and 50% of long-term mean annual rainfall 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. Thus, while our study predicts dire environmental consequences if rain-index insurance is introduced in its presently advocated form with relatively high strike levels, our study also suggests modifications in the insurance design that will alleviate these problems. If the strike level is lowered considerably – to a level of about 30% long-term mean annual rainfall – 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 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%.

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 people so far rely on natural insurance through particular forms of ecosystem management, 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. Only an explicit consideration of these feedback dynamics avoids negative consequences on the state of ecosystems and, thereby, on farmers' economic wealth in the long-run.

References

Barnett, B. J. and O. Mahul (2007). Weather index insurance for agriculture and rural areas in lower-income countries. *American Journal of Agricultural Economics*, **89**:

1241–1247.

Barnett, B. J., C. B. Barrett, and J. R. Skees (2008). Poverty traps and index-based risk transfer products. *World Development*, **36**: 1766–1785.

Baumgärtner, S. (2007). The insurance value of biodiversity in the provision of ecosystem services. *Natural Resource Modeling*, **20**: 87–127.

Baumgärtner, S. and M. F. Quaas (2009a). Agro-biodiversity as natural insurance and the development of financial insurance markets. In *Agrobiodiversity, Conservation and Economic Development*, pp. 293–317. Routledge, London, UK.

Baumgärtner, S. and M. F. Quaas (2009b). Ecological-economic viability as a criterion of strong sustainability under uncertainty. *Ecological Economics*, **68**: 2008–2020.

Berg, A., P. Quirion and B. Sultan (2009). Weather-index drought insurance in Burkina-Faso: assessment of its potential interest to farmers using historical data. *Weather, Climate, and Society*, **preprint**(2009): 0000.

Bhattacharya, H. and D. Osgood (2008). Index insurance and common property pastures. Department of Economics Working Paper Series 2008-21, University of Utah.

Di Falco, S., J.-P. Chavas and M. Smale (2007). Farmer management of production risk on degraded lands: wheat diversity in Tigray region, Ethiopia. *Agricultural Economics*, **36**: 147–156.

Di Falco, S. and C. Perrings (2003). Crop genetic diversity, productivity and stability of agroecosystems: a theoretical and empirical investigation. *Scottish Journal of Political Economy*, **50**: 207–216.

Di Falco, S. and C. Perrings (2005). Crop biodiversity, risk management and the implications of agricultural assistance. *Ecological Economics*, **55**: 459–466.

Ehrlich, J. and G. S. Becker (1972). Market insurance, self-insurance and self-protection. *Journal of Political Economy*, **80**: 623–648.

Garman, M., C. Blanco, and R. Erickson (2000). Seeking a Standard Pricing Model. *Environmental Finance*.

Hanley, T. A. (1979). Application of an herbivore-plant model to rest-rotation grazing management on shrub-steppe rangeland. *Journal of Range Management*, **32**: 115–118.

Hazell, P. B. R. (1992). The appropriate role of agricultural insurance in developing countries. *Journal of International Development*, **4**: 567–581.

Heady, H. F. (1999). Perspectives on rangeland ecology and management. *Rangelands*, **21**: 23–33.

Hess, U., K. Richter and A. Stoppa (2002). Weather risk management for agriculture and agri-business in developing countries. In *Climate risk and the weather market, financial risk management with weather hedges*. Risk Books, London, UK.

Horowitz, J. K. and E. Lichtenberg (1993). Insurance, moral hazard and chemical use in agriculture. *American Journal of Agricultural Economics*, **75**: 926–935.

Lagarias, J., J. A. Reeds, M. H. Wright and P. E. Wright (1998). Convergence Properties of the Nelder-Mead Simplex Method in Low Dimensions. *SIAM Journal of Optimization*, **9**(1): 112–147.

Linnerooth-Bayer, J., R. Mechler and G. Pflug (2005). Refocusing disaster aid. *Science*, **309**: 1044–1046.

Mahul, O. (2001). Optimal insurance against climatic experience. *American Journal of Agricultural Economics*, **83**: 593–604.

Miranda, M. J. and D. V. Vedenov (2001). Innovations in agricultural and natural disaster insurance. *American Journal of Agricultural Economics*, **83**: 650–655.

Müller, B., K. Frank and C. Wissel (2007). Relevance of rest periods in non-equilibrium rangeland systems - a modelling analysis. *Agricultural Systems*, **92**: 295–317.

Nieuwoudt, W. L. (2000). An economic evaluation of a crop insurance programme for small-scale commercial farmers in South Africa. *Agrekon*, **39**: 269–291.

Noy-Meir, I. (1982). Stability of plant-herbivore models and possible applications to savanna. In B. Huntley and B. Walker (eds.), *Ecology and tropical savannas*, pp. 591–609. Springer, Berlin.

Olbrich, R., M. F. Quaas and S. Baumgärtner (2009). Sustainable use of ecosystem services under multiple risks – a survey of commercial cattle farmers in semi-arid rangelands in Namibia. *University of Lüneburg Working Paper Series in Economics*, Working Paper No. 137, September 2009.

Quaas, M. F. and S. Baumgärtner (2008). Natural vs. financial insurance in the management of public-good ecosystems. *Ecological Economics*, **65**: 397–406.

Quaas, M. F., S. Baumgärtner, C. Becker, K. Frank and B. Müller (2007). Uncertainty and sustainability in the management of semi-arid rangelands. *Ecological Economics*, **62**: 251–266.

Quirk, M. (2002). Managing grazing. In A. Grice and K. Hodgkinson (eds.), *Global rangelands: progress and prospects*, pp. 131–145. University Press, Oxford.

Sandford, S. (1982). Pastoral strategies and desertification: opportunism and conservation in dry lands. In B. Spooner and H. Mann (eds.), *Desertification and Development*, pp. 61–80. Academic Press, London.

Skees, J. R. and B. J. Barnett (1999). Conceptual and practical considerations for sharing catastrophic/systemic risks. *Review of Agricultural Economics*, **21**: 424–441.

Skees, J. R., P. Varangis, D. Larson and P. Siegel (2002). Can financial markets be tapped to help poor people cope with weather risks? Technical report, World Bank, Washington DC.

Sullivan, S. and R. Rohde (2002). On non-equilibrium in arid and semi-arid grazing systems. *Journal of Biogeography*, **29**: 1595–1618.

Turvey, C. G. (2001). Weather derivatives for specific event risks in agriculture. *Review of Agricultural Economics*, **23**: 333–351.

UNCCD (2008). Fact Sheet 3 – The Consequences of Desertification. `http://www.unccd.int`, accessed October 15, 2009.

UNCCD (2009). Land Degradation Central to a Looming Storm, Scientists Warn. News Release No.04/09, `http://www.unccd.int`, accessed October 15, 2009.

United Nations (2007). Developing index-based insurance for agriculture in developing countries. *United Nations. Sustainable Development Innovation Briefs*.

Westoby, M., B. H. Walker and I. Noy-Meir (1989). Opportunistic management for rangelands not at equilibrium. *Journal of Range Management*, **42**: 266–274.

WFP (2006). News release: World's first humanitarian insurance policy issued. `http://www.wfp.org`, accessed October 15, 2009.

Widawsky, D. and S. D. Rozelle (1998). Varietal diversity and yield variability in Chinese rice production. In M. Smale (ed.), *Farmers, Gene Banks, and Crop Breeding. Economic Analyses of Diversity in Wheat, Maize, and Rice*, pp. 159–172. Kluwer, Boston.

WorldBank (2005). Managing agricultural production risk. *World Bank*, **32727-GLB**.

Wu, J. J. (1999). Crop insurance, acreage decisions, and nonpoint-source pollution. *American Journal of Agricultural Economics*, **81**: 305–320.

Zeuli, K. A. and J. Skees (2005). Rainfall Insurance: A Promising Tool for Drought Management. *Water Resources Development*, **21**: 663–675.

Acknowledgments

Financial support from the Volkswagen Foundation under grants II/79 628 and II/82 883 and from the German Federal Ministry of Education and Research under grant 01UN0607 is gratefully acknowledged.

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]In general, the strike level p^{ins} is different from the threshold p^{gr} above which stocking is reduced under the grazing management strategy $(\alpha, p^{\mathrm{gr}})$.

[3]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.

Working Paper Series in Economics

(recent issues)

No.148: *Alexander Vogel, Florian Burg, Stefan Dittrich und Joachim Wagner:* Zur Dynamik der Export- und Importbeteiligung deutscher Industrieunternehmen – Empirische Befunde aus dem Umsatzsteuerpanel 2001-2006, Oktober 2009

No.147: *Markus Groth:* Potentiale und Risiken der Nutzung von Methan aus Methanhydraten als Energieträger, Oktober 2009

No.146: *Sandra Derissen, Martin Quaas and Stefan Baumgärtner:* The relationship between resilience and sustainable development of ecological-economic systems, October 2009

No.145: *Anne-Kathrin Last und Heike Wetzel:* Effizienzmessverfahren – Eine Einführung, September 2009

No.144: *Horst Raff and Joachim Wagner:* Intra-Industry Adjustment to Import Competition: Theory and Application to the German Clothing Industry, September 2009

No.143: *Nils Braakmann:* Are there social returns to both firm-level and regional human capital? – Evidence from German social security data. September 2009

No.142: *Nils Braakmann and Alexander Vogel:* How does economic integration influence employment and wages in border regions? The case of the EU-enlargement 2004 and Germany's eastern border, September 2009

No.141: *Stefanie Glotzbach and Stefan Baumgärtner:* The relationship between intra- and intergenerational ecological justice. Determinants of goal conflicts and synergies in sustainability policy. September 2009

No.140: *Alexander Vogel:* Exportprämien unternehmensnaher Dienstleister in Niedersachsen, September 2009

No.139: *Alexander Vogel:* Die Dynamik der Export- und Importbeteiligung niedersächsischer Industrieunternehmen im interregionalen Vergleich 2001-2006, September 2009

No.138: *Stefan Baumgärtner and Martin F. Quaas:* What is sustainability economics? September 2009

No.137: *Roland Olbrich, Martin F. Quaas and Stefan Baumgärtner:* Sustainable use of ecosystem services under multiple risks – a survey of commercial cattle farmers in semi-arid rangelands in Namibia, September 2009

No.136: *Joachim Wagner:* One-third codetermination at company supervisory boards and firm performance in German manufacturing industries: First direct evidence from a new type of enterprise data, August 2009

No.135: *Joachim Wagner:* The Reasearch Potential of New Types of Enterprise Data based on Surveys from Official Statistics in Germany, August 2009

No.134: *Anne-Kathrin Last and Heike Wetzel:* The Efficiency of German Public Theaters: A Stochastic Frontier Analysis Approach, July 2009

No.133: *Markus Groth:* Das Conservation Reserve Program: Erfahrungen und Perspektiven für die europäische Agrarumweltpolitik, Juli 2009

No.132: *Stefan Baumgärtner and Sebastian Strunz:* The economic insurance value of ecosystem resilience, July 2009

No.131: *Matthias Schröter, Oliver Jakoby, Roland Olbrich, Marcus Eichhorn and Stefan Baumgärtner:* Remote sensing of bush encroachment on commercial cattle farms in semi-arid rangelands in Namibia, July 2009

No.130: *Nils Braakmann:* Other-regarding preferences, spousal disability and happiness: Evidence for German Couples, May 2009

No.129: *Alexander Vogel and Joachim Wagner:* Exports and Profitability – First Evidence for German Services Enterprises, May 2009

No.128: *Sebastian Troch:* Drittelbeteiligung im Aufsichtsrat – Gesetzliche Regelung versus Unternehmenspraxis. Ausmaß und Bestimmungsgründe der Umgehung des Drittelbeteiligungsgesetzes in Industrieunternehmen, Mai 2009

No.127: *Alexander Vogel:* The German Business Services Statistics Panel 2003 to 2007, May 2009
[forthcoming in: Schmollers Jahrbuch 129 (2009)]

No.126: *Nils Braakmann:* The role of firm-level and regional human capital fort he social returns to education – Evidence from German social security data, April 2009

No.125: *Elke Bertke und Markus Groth:* Angebot und Nachfrage nach Umweltleistungen in einem marktanalogen Agrarumweltprogramm – Ergebnisse einer Pilotstudie, April 2009

No.124: *Nils Braakmann and Alexander Vogel:* The impact of the 2004 EU-enlargement on enterprise performance and exports of service enterprises in the German eastern border region, April 2009
[revised version forthcoming in: Review of World Economics]

No.123: *Alexander Eickelpasch and Alexander Vogel:* Determinants of Export Behaviour of German Business Services Companies, March 2009

No.122: *Maik Heinemann:* Stability under Learning of Equilibria in Financial Markets with Supply Information, March 2009

No.121: *Thomas Wein*: Auf der Speisekarte der DPAG: Rechtliche oder ökonomische Marktzutrittsschranken? März 2009

No.120: *Nils Braakmann und Joachim Wagner:* Product Diversification and Stability of Employment and Sales: First Evidence from German Manufacturing Firms, February 2009

No.119: *Markus Groth:* The transferability and performance of payment-by-results biodiversity conservation procurement auctions: empirical evidence from northernmost Germany, February 2009

No.118: *Anja Klaubert:* Being religious – A Question of Incentives? February 2009

No.117: *Sourafel Girma, Holger Görg and Joachim Wagner:* Subsidies and Exports in Germany. First Evidence from Enterprise Panel Data, January 2009

No.116: *Alexander Vogel und Joachim Wagner:* Import, Export und Produktivität in niedersächsischen Unternehmen des Verarbeitenden Gewerbes, Januar 2009

No.115: *Nils Braakmann and Joachim Wagner:* Product Differentiation and Profitability in German Manufacturing Firms, January 2009

No.114: *Franziska Boneberg:* Die Drittelmitbestimmungslücke im Dienstleistungssektor: Ausmaß und Bestimmungsgründe, Januar 2009
[revidierte Version erscheint in: Zeitschrift für Industrielle Beziehungen]

No.113: *Institut für Volkswirtschaftslehre:* Forschungsbericht 2008, Januar 2009

No.112: *Nils Braakmann:* The role of psychological traits and the gender gap in full-time employment and wages: Evidence from Germany. January 2009

No.111: *Alexander Vogel:* Exporter Performance in the German Business Services Sector: First Evidence from the Services Statistics Panel. January 2009
[revised version forthcoming in: The Service Industries Journal]

No.110: *Joachim Wagner:* Wer wird subventioniert? Subventionen in deutschen Industrieunternehmen 1999 – 2006. Januar 2009

No.109: *Martin F. Quaas, Stefan Baumgärtner, Sandra Derissen, and Sebastian Strunz:* Institutions and preferences determine resilience of ecological-economic systems. December 2008

No.108: *Maik Heinemann:* Messung und Darstellung von Ungleichheit. November 2008

No.107: *Claus Schnabel & Joachim Wagner:* Union Membership and Age: The inverted U-shape hypothesis under test. November 2008

No.106: *Alexander Vogel & Joachim Wagner:* Higher Productivity in Importing German Manufacturing Firms: Self-selection, Learning from Importing, or Both? November 2008
[revised version forthcoming in: Review of World Economics]

No.105: *Markus Groth:* Kosteneffizienter und effektiver Biodiversitätsschutz durch Ausschreibungen und eine ergebnisorientierte Honorierung: Das Modellprojekt „Blühendes Steinburg“. November 2008

No.104: *Alexander Vogel & Joachim Wagner:* Export, Import und Produktivität wissensintensiver KMUs in Deutschland. Oktober 2008

No.103: *Christiane Clemens & Maik Heinemann:* On Entrepreneurial Risk – Taking and the Macroeconomic Effects Of Financial Constraints, October 2008

No.102: *Helmut Fryges & Joachim Wagner*: Exports and Profitability – First Evidence for German Manufacturing Firms. October 2008

No.101: *Heike Wetzel*: Productivity Growth in European Railways: Technological Progress, Efficiency Change and Scale Effects. October 2008

No.100: *Henry Sabrowsk*i: Inflation Expectation Formation of German Consumers: Rational or Adaptive? October 2008

No.99: *Joachim Wagner*: Produktdifferenzierung in deutschen Industrieunternehmen 1995 – 2004: Ausmaß und Bestimmungsgründe, Oktober 2008

No.98: *Jan Kranich:* Agglomeration, vertical specialization, and the strength of industrial linkages, September 2008

No.97: *Joachim Wagner:* Exports and firm characteristics - First evidence from Fractional Probit Panel Estimates, August 2008

No.96: *Nils Braakmann:* The smoking wage penalty in the United Kingdom: Regression and matching evidence from the British Household Panel Survey, August 2008

No.95: *Joachim Wagner:* Exportaktivitäten und Rendite in niedersächsischen Industrieunternehmen, August 2008
[publiziert in: Statistische Monatshefte Niedersachsen 62 (2008), 10,552-560]

No.94: *Joachim Wagner:* Wirken sich Exportaktivitäten positiv auf die Rendite von deutschen Industrieunternehmen aus?, August 2008
[publiziert in: Wirtschaftsdienst, 88 (2008) 10, 690-696]

(see www.leuphana.de/vwl/papers for a complete list)

Leuphana Universität Lüneburg
Institut für Volkswirtschaftslehre
Postfach 2440
D-21314 Lüneburg
Tel.: ++49 4131 677 2321
email: brodt@leuphana.de
www.leuphana.de/vwl/papers