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by

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Determinants and interactions of sustainability and risk management of commercial cattle farmers in Namibia

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Abstract:

We study the determinants and interactions of sustainability and risk management with a cross-sectional dataset on commercial cattle farming in semi-arid rangelands in Namibia. Cattle farmers in Namibia act within a coupled ecological-economic system that is subject to extensive degradation and high environmental risk. Based on survey data, we develop variables for sustainability and risk management within this context, identify their determinants and analyse relevant interactions. Our results show that the ecosystem condition is positively influenced when financial risk management strategies are applied. On-farm risk management, like additional feed for cattle or resting part of the rangeland, and collective risk management through interest groups or governmental support, instead, do not impact on the sustainability of the farm. Risk management itself is predominantly influenced by various risks linked to the farming business and the farmers' educational background. Furthermore, the gathered experience through operation time on farm decreases the application of on-farm risk management and favours the use of financial and collective risk management. Additionally, collective risk management is influenced by risk preferences, indicating that farmers who are more risk friendly apply forms of joint risk management strategies to a lesser extent. Risk friendliness is also negatively related to the economic sustainability, specified as the ability to sustain the livelihood of the farmer. However, the results show no indication whatsoever that time preferences impact on either sustainability or risk management.

Keywords:

cattle farming, ecological-economic system, financial instruments, precipitation, risk management, semi-arid rangelands, sustainability

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1. Introduction

Livestock farming in Namibia takes place in an extensively degraded ecosystem where the provision of ecosystem services is subject to uncertainties (cf. Olbrich et al. 2014, 7). Studying sustainability of farms together with risk management that mitigates adverse effects for the farmers from uncertainties, the present analysis addresses crucial aspects of commercial cattle farming.

Agriculture in Namibia takes place on semi-arid rangelands and is strongly influenced by climatological conditions, soil composition and population density. More than two thirds of Namibia's population depend directly or indirectly on agriculture (cf. Schröter et al. 2011, 2). Thus, agriculture is seen as a crucial sector to reduce poverty in Africa and reach the Millennium Development Goals (MDGs). In fact, all MDGs do either directly or indirectly relate to agriculture (cf. FAO 2011, XIV). As a consequence, agriculture is assigned an important role in reducing poverty and malnourishment and improving economic development in African countries like Namibia.

47.1% of the total area in Namibia is used for diverse agricultural purposes (cf. FAO 2012, 42). The country's climate is dry and hot, with low and highly variable precipitation amounts, both spatial and seasonal (cf. WKÖ 2012). Namibia is classified as the driest country in sub-Saharan Africa with approximately 270 mm annual rainfall. Furthermore, the annual rainfall distribution is right skewed, featuring comparatively more rainfall years below average than above average (cf. Sweet & Burke 2006). There is a single wet season every year from November till April where the biggest share of precipitation occurs (cf. Olbrich et al. 2012, 3). Due to these ecological land features the agricultural potential of the major part of Namibia's area is restricted to livestock farming (cf. Sweet & Burke 2006). Livestock farming is by far the most dominant sector in the agribusiness with commercial cattle farming being one prime example (cf. Botschaft der Republik Namibia 2010). With almost 50%, commercial cattle farming holds the biggest share of Namibia's agricultural output (cf. MAWF 2009, 10). In 2011, 2.4 m cattle were held on Namibian farms (cf. FAO Statistics Division 2013).

Cattle farming in Namibia is characterised by a largely degraded system (cf. Olbrich et al. 2014, 6). Research shows, that the grazing capacity in Namibia is changing over time and a degradation process takes place. The average grazing capacity of 0.08 Large Stock Units (LSU) per hectare (ha) is much lower than 50 years ago, until 1964 with 0.12 LSU/ha (cf. de Klerk 2004, 21). Most cattle farms are situated in the central-northern parts of the country where the carrying capacity of the rangelands is still significantly higher. The natural pasture of the rangeland is the main forage for livestock (cf. Sweet 1998, 4). Big challenges for cattle farming in those semi-arid rangelands are drought and the lack of surface water. In order to avoid overgrazing and be provided with sufficient forage, cattle require large areas of rangeland. Namibian farms are therefore very large, on average 7,544 ha, whereby cattle are raised under extensive ranching conditions (cf. Sweet & Burke 2006; Olbrich et al. 2014, 6).

Taking this complex and stressed system as a case study, the present work tries to analyse crucial drivers for sustainability and management behaviour of the farmers. The following Section 2 focusses on the relevance of the topic and the research aims that outline the work. Section 3 presents the used dataset and the applied methods. In Section 4 the main results are explained, responding to the initial research questions. Section 5 assures the validity of the results through statistical tests and model robustness. Finally, Section 6 concludes the work by discussing its results.

2. Topic relevance and research aims

While the agricultural sector and amongst it especially cattle farming is of essential significance, there is a general lack of statistics and research data concerning this sector (cf. FAO 2011, VI). Aspects relating to sustainability and risk management are in special need of further research (cf. Olbrich et al. 2012, 2). Nonetheless, sustainability and risk management play a vital role for the past, present and future development of cattle farming in Namibia.

Commercial cattle farmers in Namibia act in a coupled ecological-economic system. This refers to the direct impact of the ecosystem condition on the economic subsystem (cf. Schröter et al. 2011, 2). As the ecological and economic systems are tightly coupled, grazing management marks a major field of research for ecological economists (cf. Quaas et al. 2007, 251). The ecosystem itself defines the economic output a farmer can generate with his[1] cattle by producing green grass biomass. The cattle directly feed on the pasture of the rangeland with livestock being the main source of income for the farmers. Consequently, farmers benefit from this ecosystem service as it sustains their livelihood. Thus, the amount of income derived from cattle farming strongly depends on the ecological conditions of the rangeland (cf. Quaas et al. 2007, 251). Based on this direct dependence, the farmers rely heavily upon a

[1] For the sake of simplicity, references to persons will always be given in the masculine form. This, however, is no indication of a gender-related preference. Both female and male genders are covered by the references.

well-functioning ecosystem (cf. Olbrich et al. 2009, 3). The coupled ecological-economic system in semi-arid rangelands is very sensitive towards the low and simultaneously highly variable precipitation rates (cf. Quaas et al. 2007, 252).

Owing to these climatic conditions, overgrazing is a likely consequence of cattle farming which leads to a follow-up problem: increasing bush cover on the rangeland. Bush encroachment is regarded as one of the most extensive land cover changes and classified as an urgent problem for cattle farming (cf. Schröter et al. 2011, 2). Radically overgrazed areas are repopulated by bushes, commonly acacia bushes (cf. De Klerk 2004, 91f.). Bush encroachment is widely problematic since the bushes dehumidify the soil as their water demand is much higher than that of green grass biomass (cf. Sweet & Burke 2006; De Klerk 2004, 6f.). Cattle usually cannot penetrate the bushes to reach the low growing grass. This reinforces the pressure on the remaining bush-free grasslands, which in turn stimulates more bush encroachment. A viscous circle of further rangeland degradation begins.

Land degradation through bush encroachment is a process that may be caused by human or nature or both (cf. UNCCD 2013, 4). One major reason for the degradation of the system appears to be inadequate farm management (cf. Olbrich et al. 2014, 3). As the ecosystem itself, is extremely vulnerable and sensitive to exogenous influences, the ecosystem service provision is limited by various risks, like low and highly variable rainfall or bush encroachment. To counteract these risks and thereby assure a satisfying income from farming, farmers can apply risk management strategies. As a result, the ecosystem can either be stabilized or become degraded, e.g. through grazing pressure. Hence, the ecosystem is directly influenced by its economic use and environmental conditions.

This tightly coupled and sensitive ecological-economic system features numerous interdependencies and interactions between socio-demographic aspects, farm business specific factors, farm management strategies and individual characteristics, combined with exogenous influencing factors. Within this complex system, the present study tries to analyse the sustainability of the farm and the applied management strategies to reduce environmental and income risks for the farmers. Our work measures sustainability for this specific case study. Furthermore, we analyse by which factors sustainability is driven. Thereby, special attention is concentrated on the influence of risk management strategies on the farm’s sustainability. In a second step, risk management strategies and their determinants are examined more closely with specific focus on whether and how risk management is shaped by ecological and economic sustainability on farms. Since they are modifiable parameters, farmers can influence them to cope with specific challenges they encounter within this coupled ecosystem.

The scope of the work is the examination of the following research questions:

(1) How can sustainability and risk management strategies be characterized within the study context?

(2) What determines the sustainability of the farm? Do risk management strategies impact on the sustainability condition and if so, in what way?

(3) What determines the application of risk management strategies of the farmer? Does sustainability influence the importance of management strategies and if so, in what way?

3. Data and methods[2]

To analyse sustainability and risk management, data from a survey presented in Section 3.1 is used. Based on the survey, variables for sustainability and risk management are constructed. This is elaborated on in Sections 3.2 and 3.3. Section 3.4 presents the applied methods for the development of the final regression models. Elicited variables for the identification of the best subset of predictors for sustainability and risk management are described in Section 3.5.

3.1. Survey conduction and dataset

The present analysis is based on research data from a survey by the University of Lüneburg in co-operation with the Namibian Agricultural Union (NAU) – the main interest group of farmers in Namibia. The survey was conducted in August/September 2008 among 2,119 commercial cattle farmers (cf. Olbrich et al. 2009, 4). With this survey approximately 77% of all estimated 2,500 commercial cattle farmers in Namibia could be reached. 398 questionnaires were completed and sent back, which equals a return rate of over 20%. As a database for all commercial cattle farmers does not exist, the case study provides data from two different samples: the NAU as co-operating partner and MeatCo., Namibia's largest slaughterhouse and meat processing company (cf. Olbrich et al. 2014, 19; Olbrich et al. 2009, 1ff.). The datasets show no significant difference in important socio-demographic characteristics (cf. Olbrich et al. 2009). A description of the sample structure is conducted as a tabulation of the descriptive characteristics of all constructed variables (see Appendix B, Tab.1).

[2] For all data analyses the statistical software Stata 12 by StataCorp LP was used, see: www.stata.com.

The survey is representative for the population of commercial cattle farmers except for location of the farm and ethnicity as indigenous subpopulations are undersampled (cf. Olbrich et al. 2009, 21).[3] In addition, the survey could be biased with respect to farmers not belonging to their main interest group. This is a result of the survey construction and the historical roots of the NAU, founded in a time when commercial farming was conducted only by white people (cf. Olbrich et al. 2009, 10; Muenjo & Mapaure 2010, 71). Lastly, the data might be biased with respect to a predisposition in a certain Weltanschauung due to NAU membership. Because the NAU as an interest group is committed to the support and expansion of cattle farming in Namibia (cf. Olbrich et al. 2009, 22).

3.2. Elicitation of sustainability

Sustainability is indicated by the capability of the ecosystem to provide an ecosystem service and as a consequence to ensure a sufficiently high income from cattle farming. Therefore, in the present analysis the concept of sustainability is composed of two variables: an ecological component and an economic component. Relating sustainability norms to actual ecosystem and economic conditions provides the basis for the two sustainability variables. Norms of sustainability with a conceptual background for this specific study were worked out by Olbrich et al. (2014).

3.2.1. Ecological sustainability

Ensuring ecological sustainability implies maintaining the ecological service the ecosystem provides. In the conducted analysis, the production of green grass biomass ensures the grazing capacity on the farmland (cf. Lukomska et al. 2014, 2f.). The notion of strong sustainability is only given, if this ecosystem service is sustained at a certain threshold level (cf. Ekins et al. 2003; Olbrich et al. 2014, 5). The concept of strong ecological-economic sustainability within this context is elaborated on by Olbrich et al. (2014). The considered ecosystem in this analysis is kept stable by maintaining its ecosystem service. The biomass production, though, is severely constrained by bush encroachment (cf. Schröter et al. 2011, 2f.). Thus, the level of bush cover on the rangeland can be used as an indicator for the ecosystem's condition (cf. Olbrich et al. 2014, 7).

[3] The survey is also intentionally biased with respect to living on farm concerning the in-field experiments. As we do not consider the questions derived from these experiments, this bias does not affect our analysis.

To construct the variable for ecological sustainability, the actual bush cover as limiting factor for the grass production is combined with the individually indicated threshold level of bush encroachment. As the actual bush cover was collected in the six intervals [0%], [1 to 20%], [21 to 40%], [41 to 60%], [61 to 80%] and [81 to 100%], we converted the data to discrete point data by using the mid-points of the intervals. The individual threshold level shows the amount of bush cover perceived as optimum by each farmer for the respective farmland. Thus, the amount of ecological service that should be maintained is based on a personal assessment of the sustainable bush cover fraction for each farm individually. The threshold level correlates with the farmer's personal norm of ecological sustainability, derived from the following question of the survey:

> "Sustaining the natural environment by sustaining the grazing capacity of your rangeland: How high should the grazing capacity of your rangeland, expressed in hectares per large stock unit, be during your own and future generations?"

This difference between the perceived optimal level of bush cover and the actual level of bush encroachment serves as variable for ecological sustainability, with higher values showing a more sustainable ecological system: If the variable for ecological sustainability is smaller than zero the actual bush cover exceeds the optimal bush cover. The bigger the surplus of actual bush cover, the more unsustainable farming is deemed. If the variable is equal to zero the actual bush cover is equal to the optimal bush cover which indicates sustainable farming. For all positive values the actual bush cover is smaller than the indicated optimum. Owing to this smaller fraction of bush cover, the desirable production of green grass biomass is not limited to a suboptimal amount (cf. Lukomska et al. 2014, 6f.; De Klerk 2004, 58ff.). Still, fewer bush encroachment does not necessarily indicate a better ecosystem condition (cf. Lukomska et al. 2014, 3f.). In a sustainable system, there would be a balanced coexistence of grass and bush vegetation. As there is no thorough interpretation possible, when the optimum surmounts the actual bush cover, the variable for ecological sustainability is censored at the state of sustainability, zero. The variable only includes farmers who have operated at least for five years on their farm. This allows for the farmers' management to have an influence on the condition of the ecosystem, besides exogenous influencing factors like precipitation or farm location.

To validate the variable for ecological sustainability, its relation to other variables reflecting the ecological state of the rangeland is analysed. The ecological sustainability is significantly positively correlated with the personal rating of the quality of rangeland. Further analysis discloses that the land quality and the location of the rangeland are not significantly correlated. Thus, the rating of the farmland quality does not exclusively reflect the region-specific land quality but rather its ecological quality in general. In addition, the ecological sustainability variable is significantly positively correlated with the difference between the actual grazing capacity on the farm and the optimal grazing capacity in ha/LSU as indicated by the farmer.

3.2.2. Economic sustainability

The notion of strong sustainability does not only ensure the production of green grass biomass but also holds the farmer's income above a certain threshold level, regardless of whether stock and service are directly connected or not (cf. Olbrich et al. 2014, 6). In the broached issue of commercial cattle farming in Namibia, stock and service are tightly linked to each other: To ensure ecological sustainability the production of green grass biomass has to be maintained as it ensures the grazing capacity on the farmland. This in turn provides forage for livestock and eventually generates income for the farmer. Bush encroachment, though, through a reduction in green grass biomass production, severely limits the profitability of cattle farming (cf. Sweet 1998, 5f.). The direct economic dependence of the farmer on a well-functioning ecosystem that steadily provides an ecosystem service illustrates the tightly coupled ecological-economic system in which commercial cattle farming takes place.

To construct the variable for economic sustainability the actual income is combined with the individually indicated threshold level for an annual income from cattle farming. As the total annual income was collected in the following intervals [N$ 0 to N$ 50,000], [N$ 50,001 to N$ 150,000], [N$ 150,001 to N$ 250,000], [N$ 250,001 to N$ 350,000] and [N$ 350,000 to ∞[, we converted the data to discrete point data by using the mid-points of all closed intervals and N$ 400,000 for the last interval.[4] According to Olbrich et al. (2014, 12), these values are being corrected for the income fraction derived from cattle farming. The individual threshold level for income from cattle farming shows the needed amount of income in order to conduct an economically sustainable farming business. This level is based upon a personal assessment of each farmer individually. The threshold level accords with the personally set norm for income sustainability, derived from the following question in the survey:

> "Sustaining the livelihood of farmers by sustaining income: How much annual net income (gross revenues from farming minus operating expenses, taxes and interest on

[4] N$ 1,000 equalled 88.14€ on 1st August 2008.

loans), expressed in today’s N$, should your yourself and future generations at least derive from cattle farming?”

The difference between the perceived optimal amount of income from farming and the actual income level serves as the variable for economic sustainability, with higher values showing an economically more sustainable state. If the variable for economic sustainability is smaller than zero the actual income is below the needed threshold level. The bigger this deficit becomes, the more unsustainable the farming is deemed. If the variable is equal to zero, the actual income is in accord with the indicated optimum which is an indicator for sustainable farming. For all positive values the actual income from cattle farming exceeds the income threshold. Generating more income than needed to sustain the livelihood of the farmers indicates economic sustainability but not necessarily to a higher extent. As there is no reasonable interpretation possible for all positive values of the variable, an upper limit at zero is set. Thus, analogue to ecological sustainability, a state of economic sustainability is reached when the variable equals zero. In this case, the income threshold is equal to or smaller than the farmer’s actual income. Likewise, only those farmers are included who at least operated for five years on their farm.

3.3. Elicitation of risk management strategies

Risk management strategies cope with the uncertain provision of ecosystem services. How severely farmers are affected by the uncertainty of the ecosystem service provision depends on their risk perceptions and its handling (cf. Olbrich et al. 2009, 2). By applying different strategies the farmers are able to monitor and manage risks that are associated with the farming business. Hence, those strategies represent essential instruments to cope with the predominant risk of low rainfall (see Section 2). Based on the survey data, risk management strategies are captured in three different groups: on-farm, financial and collective risk management; which form the three variables described in the following.

On-farm management strategies are ecological strategies that influence the production process (cf. Olbrich et al. 2009, 8). The variable for on-farm management includes the following six strategies derived from the survey questionnaire: purchase of supplementary feed, choice of cattle production system (e.g. oxen production), choice of breed adapted to high variability in grass production, resting part of the rangeland in good rainy seasons to build up buffers for bad seasons, purchase or lease of extra rangeland in areas with different rainfall patterns and purchase or lease of extra rangeland for scale effects. The strategies are elicited on a six-item Likert-scale indicating the extent to which each management strategy is applied within the range from “not at all important” to “very important”. To construct the variable for on-farm risk management an overall mean of all six strategies is calculated. The aggregation of all strategies is validated by correlation analysis. As all strategies show significant positive correlations with each other, an unweighted average for the final variable is deemed reasonable.

Financial and collective risk management strategies are socio-economic strategies (cf. Olbrich et al. 2009, 8). The variable for financial risk management includes the subsequent six strategies, that are as well derived from the questionnaire: forward contracts for fixing a good price, advances on livestock sales, savings or checking account as a financial buffer, uptake of loans for covering operating losses, income from off-farm employment and off-farm assets and investment into agricultural derivatives on the stock market. Elicitation, as well, took place on a six-item Likert-scale indicating the extent of strategy application from “not at all important” to “very important”. To construct the variable for financial risk management an overall mean is calculated and validated by correlation analysis. As all six strategies show significant positive correlations with each other, an unweighted average for the final variable is calculated.

The variable for collective risk management includes the three strategies: governmental support such as subsidies or drought relief, interest groups on a local level (e.g. conservancy groups) and interest groups on a national level (e.g. NAU or parties). All strategies were elicited on a six-item Likert-scale indicating the extent of strategy application ranging from “not at all important” to “very important”. The construction of the variable for collective risk management equals the average value of the three strategies and was further validated by correlation analysis. Owing to significant correlations an unweighted average value is calculated. A fourth strategy for cooperative ownership of farmland was omitted in the variable construction. This is ascribed to its missing correlation with the strategy of national interest groups and its low overall importance, which can be traced back to the small fraction of farmers (2.3%) with cooperative ownership structure (Olbrich et al. 2012, 12f.). Hence, the variable for collective risk management only consists of the first three above enlisted strategies.

In accordance with Olbrich et al. (2014, 7f.), the variables for on-farm, financial and collective risk management are considered as quasi-continuous variables. To assure this argument robustness checks and alternative scales for all three risk management variables are conducted in the later analyses (see Sections 5.3–5.6).

3.4. Development of regression models

To identify the best subset of predictors for each dependent variable a stepwise forward regression process is conducted and complemented by literature review and correlation analysis. The stepwise forward regression algorithm according to Efroymson (1960) starts with an empty model, only containing the constant term and no further predictors. All possible determinants are sorted according to their explanatory power for the dependent variable. The insertion of new variables is based on the partial correlation coefficient of the predictors with the dependent variable (cf. Draper & Smith 1981, 307f.). At each step the predictor that improves the model the most is included in the model. The addition of each new predictor is verified through removal tests (a model comparison F-test and t-test-statistics) where insignificant parameters are removed from the model (cf. Draper & Smith 1981, 307ff.). This procedure is repeated until no further variable can improve the model.

Within stepwise regression the choice of regressors is conducted by an automatic procedure. For each regression equation a stepwise regression is conducted with a significance level of 0.1 (0.2, 0.3) for the addition of predictors to the model and 0.11 (0.21, 0.31) for the removal of insignificant variables from the model. To complement this automated procedure a list of variables is elicited based on literature review and correlation analysis. Variables with a potential influence on sustainability and risk management are identified and introduced separately into the regression model. In addition to the separate introduction of individual variables, the strength and significance of correlation values between the latent variable and possible predictors and interdependencies between the different independent variables is evaluated. Based on this analysis, further predictors are added to the model in numerous combinations and alternatively to replace already included variables. Background information on the elicited variables for the models is given in Section 3.5.

By in- and excluding various predictors, the model derived by stepwise regression is compared to alternative model specifications. The importance to reflect model uncertainty for the final selected model is met by comprehensive model testing in Section 5 (cf. Chatfield 1995, 420f.).

3.5. Elicitation of socio-demographic, exogenous and further characteristics

In order to analyse sustainability and risk management properly, relevant impacting factors on the latent variables have to be identified. Based on the survey data a total of 46 possible explanation factors were developed. An impression of all created variables together with the five dependent variables for sustainability and risk management is given in Appendix A, in figure 1. To account for a better overview, the variables are clustered in five groups: socio-demographic factors, exogenous factors, farm-specific factors, individual characteristics and farm management strategies. A condensed tabulation of the descriptive characteristics of all constructed variables is conducted in Appendix B, Table 1, by displaying mean, standard deviation as well as minimum and maximum values. Based on this pool of variables, a set of relevant impacting factors for the later regression analyses is identified. Background on the elicited variables is given below. In addition, frequency tables including absolute and relative frequencies are calculated for this set of variables (see Tab.2-32). All elicited variables are included in the regression models if they maximize the explanatory power of the model while complying with all underlying model assumptions.

A dummy variable for Caucasian ethnicity is elicited as explanation factor for risk management strategies (see Tab.2). Caucasian includes farmers of Afrikaans, German and English ethnicity. Indigenous farmers are assigned to the control group. The consideration of indigenous farmers as a reference group traces back to the history of commercial cattle farming in Namibia and the historical importance of cattle especially for the Herero, the largest indigenous ethnicity (cf. Olbrich et al. 2012, 7 and Ejikeme 2011, 10). Due to possible cultural differences between indigenous and Caucasian farmers with respect to cattle farming (cf. Cocker 1998, 275ff.) the aforementioned grouping is chosen.

Concerning the educational background a variable for the level of education (see Tab.3) and four variables for the main fields of study (see Tab.4) are included in the analyses. The level of education is categorized in the two groups: no college or apprenticeship education (28.3%) and higher education (71.7%) (cf. Olbrich et al. 2011, 17). The observations showing low education are used as a control group. In order to detect distinct influences of the educational background of the farmer, the most dominant groups were identified: ecological education (39.9%), economic education (21.6%), technical education (25.2%) and education in more than one of those three fields of study (10.1%). The first three groups also include those farmers who were educated in more than one field of study. The four educational groups are used to build dummy variables with the opposite, having no distinct education in the respective field of study, being the control group.

The farmer's age is considered relevant as it was also included by Olbrich et al. (2014, 12) in a model for determining norms of sustainability for the same dataset (see Tab.5). In addition, a dummy variable for gender is included as it appears in a risk related model by Olbrich et al. (2011, 24f.) for this dataset (see Tab.6). The gender is categorized in the two groups: male (94.7%) and female (5.3%). The dummy variable tests for the impact of the male gender as the predominant group.

Regarding the high correlation between the two created income variables, total income and income from farming (Pearson: 0.715, p<0.0001), we want to include only one income measure in the analyses. Olbrich et al. (2014, 12) consider income from cattle farming as a determining factor for the norms of sustainability. Thus, income from farming is elicited for the models (see Tab.7). For the construction of the variable, see the development of discrete point data in 3.2.2. A similar issue arises for the two wealth-indicators, cattle quantity and rangeland size, which are highly correlated with each other (Pearson: 0.7414, p<0.0001). Olbrich et al. (2011) and Olbrich et al. (2014) consider the size of the rangeland as a proxy for wealth, whereas other references choose the cattle quantity as an indicator for wealth (cf. Njuki et al. 2011, 6; Olbrich et al. 2009, 19). Based on correlation analyses of both indicators with the variables for sustainability and risk management, rangeland size in ha is included as a promising predictor (see Tab.8).

As the low and uncertain precipitation is considered the predominant risk for commercial cattle farmers in Namibia (cf. Olbrich et al. 2011, 2) both precipitation measures are elicited for the regression analyses (see Tab.9-10). Precipitation data is derived from the REMO (Regional Model) climate model for the annual wet season. The data on average precipitation in mm and the coefficients of variation in precipitation[5] are available for the period of 1978 to 2008. As 75% of all farmers allowed farm identification through an optional question in the survey, it was possible to assign the local REMO data to each of those farms (see in detail: Olbrich et al. 2011, 9ff.). As both variables are highly correlated (Pearson: -0.606, p<0.0001) the variables are included separately into the models. Apart from the risk of low rainfall, variables for the rating of natural, economic, political and further risks are as well included in the analyses (see Tab.12-15). Natural risks include the risk of low groundwater levels,

[5] The standard deviation in precipitation (in mm) divided by the average amount of precipitation (in mm).

unintentional bush fires, cattle diseases and the risk of cattle loss from predators. Economic risks include the risk of unfavourable prices for cattle sales and for farming inputs, as well as the risk of rising living expenses. Political risks are composed of unfavourable trade agreements on the exports, changing labour market conditions and expropriation. The fourth variable containing further risks consists of the risk of cattle theft and the risk of machine or equipment failure. All risk variables were sampled on a six-item Likert-scale from “no risk” to “very high risk” and subsumed by calculating an average value for each farm per category.

With respect to the ecological rangeland condition, a regional dummy variable for living in an ecologically unfavourable region is elicited (see Tab.11). The variable represents all farmers living either in Erongo, Hardap, Karas, Khomas, Kunene, Omaheke or Oshikoto. Otjozondjupa, a region with favourable environmental conditions, is used as a reference group (cf. Olbrich et al. 2014, 16).

As a farm-specific factor, the dummy variable for living on farm is included in the analyses (see Tab.18). The variable for residency on farm serves as a proxy for full-time farming (cf. Olbrich et al. 2014, 12). As Olbrich et al. (2011, 25) include the ownership structure of a farm as a determining factor for risk preferences, the variable is elicited as possible predictor for risk management (see Tab.19). The dummy variable stands for a single ownership form with the reference group for joint ownership. Also, a dummy variable of whether the farmer owns his farm business or instead works as a hired manager or tenant is included (see Tab.20). The distinction was made according to Wagner & Gelübke (2012) and shows that a vast majority of farmers own their farm business (91.8%) compared to a foreign ownership (8.2%). The farm’s fate after the farmer retires is captured in three dummy variables of which the most dominant one is elicited as predictor for the analyses (see Tab.21). More than two-thirds of all farmers (67.7%) plan to bequeath their family the farming business after retirement. Deterioration or dissolving of the farm business is chosen as a reference group for this variable as the categories might yield differences in farm management behaviour. The last farm-specific factor included, deals with the operation time on farm (see Tab.22). This variable denotes the number of years the farmer operates his farm business, showing that 46.5% of all farmers already operate over 20 years on their farm.

Concerning individual characteristics, both risk and time preferences are elicited in the regression analyses (see Tab.25-26). Risk preferences are defined according to Von Neumann & Morgenstern (1944) expected utility and illustrate the farmers’ attitude towards precipitation risks, with higher values indicating risk friendliness. Both variables are derived on a nine-item Likert-scale which is modified for risk preferences by omitting the lower and upper extreme values. Through leaving out the tails of the distribution a better reflection of the farmer's risk taking behavior is sought (cf. Olbrich et al. 2011, 40f.). This decision is supported by correlation tests with other risk preference variables. Time preferences indicate the farmer's patience that increases with higher values. The selection of this variable is assured by correlation tests with other time preference variables. In addition, a dummy variable for farming until the farmer's retirement is elicited for determining sustainability (see Tab.27). As threshold age for retiring, the common retirement age in Namibia of 65 was taken into account (cf. Olbrich et al. 2012, 6). If the farmer plans to operate on his farm, at least, until he reaches his 65^{th} birth year he is considered a lifetime farmer (84.8%). The last two variables in the group of individual characteristics handle the farmer's experience captured by years of experience as owner, manager or in any other function on farm (see Tab.23) and to identify distinct influences of ownership experience a variable only containing the years of ownership is included as well (see Tab.24).

As to the importance of proper rangeland management for a sustainable farming business (cf. De Klerk 2004, 27) all three variables for risk management are included in the models for determining sustainability (see Tab.28-30). Vice versa, both sustainability variables are elicited as possible predictors in the analyses of risk management (see Tab.16-17). In addition, the on-farm management strategies for additional feed and for spatial diversification are as well elicited separately (see Tab.31-32).

4. Results

The following section presents the results of the present work with regard to our research questions. Within the final regression models in Sections 4.2 and 4.3 significant impacting factors for the dependent variables are identified by t-test statistics with their corresponding p-values.

4.1. Characterization of sustainability and risk management

The first research question deals with the characterization of sustainability and risk management. Its findings are shown below.

Both sustainability variables are based on a measurement of the present status quo combined with an individually indicated normative maxim for sustainability (see Section 3.2). Concerning ecological sustainability, the average fraction of desired bush cover is with 25.13% (std.=15.97%) significantly lower than the actual area of 40.36% (std.=22.22%) covered by bushes. This undermines the fact that cattle farming in Namibia takes places within an extensively degraded system (cf. Olbrich et al. 2014, 6). The issue is illustrated by a histogram in figure 2, with negative values indicating an undesired excess of bush encroachment and positive values showing a lack of bush cover compared to the indicated optimum. The final censored variable for ecological sustainability is found in figure 3. A similar picture unfolds when looking at economic sustainability. With N$ 274,941.4 (std.=N$ 210,206.8) the desired income threshold is 2.5 times the average amount of annual income from cattle farming, N$ 109,574.2 (std.=N$ 96,798.21). This supports previous findings that the annual net income from cattle farming is often too low to satisfy living expenses (cf. Lubbe 2007 & Peltzer 2007, cited by Olbrich et al. 2014, 6f.); a problem that was aggravated by ending agricultural subsidies with Namibian independence in 1990. Almost one third of the respondent farmers generate at least 60% of their total annual income from off-farm sources (cf. Olbrich et al. 2012, 38). The gap between desired and actual economic outcome is visualized by a histogram in figure 4, with negative values indicating a lack of income compared to the specified norm and vice versa for positive values. The final variable for economic sustainability is given in figure 5.

With respect to risk management the most important strategy is collective risk management through interest groups on a national level, like the NAU[6] or parties, with an average value of 4.98. The values are derived on a Likert-scale from 1 (‘not at all important’) to 6 (‘very important’). Owning a savings or checking account as a financial buffer plays with 4.72 the predominant role among all financial management strategies. Equally important on subsequent positions with 4.66 are the on-farm management strategies for purchase of supplementary feed and resting part of the rangeland in rainy seasons to build up buffers for bad seasons. Referring to the importance of off-farm income sources, this management strategy is with an average value of 3.98 the second most important strategy among financial risk management. With only 2.4 points on the Likert-scale, the collective management strategy for cooperative ownership of farmland possesses the lowest overall importance. Figure 6 provides average values of all risk management strategies. Among the merged strategies the collective risk

[6] In accordance with a potential survey bias for membership in likewise interest groups (see Section 3.1).

management shows the highest overall importance with 4.23 (std.=1.13). Collective risk management is followed by on-farm with 4.19 (std.=0.89) and financial risk management with 3.55 (std.=1.01). Histograms of all three final variables are given in figures 7-9.

4.2. Determinants for sustainability

This section analyses the second research question and presents the determinants for ecological and economic sustainability. In addition, Sections 4.2.1 and 4.2.2 analyse whether risk management strategies impact on ecological and economic sustainability. Which variables lead to land degradation or on the opposite enhance the securing of the ecosystem quality? Is sustainability mainly driven by exogenous factors or as well by behavioural characteristics of the farmer? The following sections try to answer these questions.

As no interdependence whatsoever between ecological and economic sustainability could be detected, both sustainability variables are analysed in two separate regression models. The inclusion of one variable in the regression model of the respective other sustainability variable showed no significant influence. In addition, this regression result stayed robust.

4.2.1. Regression model for ecological sustainability

Ecological sustainability is determined by the educational background of the farmer, his age, rangeland size, precipitation, natural risks and the application of financial risk management strategies (see Fig.10). The exact regression results are given in Appendix D, Table 33.

The farmer's age improves the ecological sustainability of the farm. With increasing age, each year the fraction of bush cover is reduced by 0.48% in proportion to the optimal level of bush cover on the rangeland. Also, if the farmer possesses a higher education i.e. at least college or apprenticeship education, the ecological sustainability of the farm is positively influenced. Better educated farmers show an 8.62% reduced excess of bush cover compared to the optimum amount. Surprisingly, an education in an ecological field of study impacts negatively on ecological sustainability. In this case, the excess of actual bush cover rises by 9.94% compared to the indicated threshold level. The fact that ecological education decreases the condition of ecosystem seems inconsistent. Out of all farmers educated in an ecological field of study 90.09% studied some form of agriculture. The faculty of agriculture at the University of

Namibia states that sustainable agricultural development and a wise use of natural resources belong to their educational objectives. But improving agricultural productivity and catalysing production are enlisted in the central objectives, as well (cf. UNAM 2013, 4). Depending on their implementation, the latter two aspects could negatively impact on the ecological enhancement and harm the condition of the ecosystem. Still, no thoroughly satisfying explanation for this issue can be identified. However, if the farmer is educated in more than one field of study a positive impact on sustainability is seen. Ecological sustainability is increased by 11.88%. The ecosystem enhancing effect of multiple educations casts a positive light on interdisciplinary education.

The rating of natural risks impacts negatively on ecological sustainability. If the relevance of risks for low groundwater levels, unintentional bush fires, cattle contracting diseases and cattle loss are increasing by one unit the sustainability of the ecosystem decreases by -4.83%. Natural risks, thus, directly affect and alter the condition of the ecosystem. Furthermore, the size of the rangeland has a slightly negative effect on sustainability. With an increase in rangeland size by one hectare, ecological sustainability decreases by 6.41e-04%. Larger rangelands allow for a more extensive farming which might increase the pressure on the ecosystem. Average annual precipitation amounts show a slightly negative effect on ecological sustainability. If the annual rainfall rises by 1 mm the excess of actual bush cover over the indicated optimal cover increases by 0.08%. Due to the high sensitivity of the ecosystem towards precipitation risks (see Section 1) a significant influence from precipitation on the sustainability of the rangeland was expected. This effect, however, contradicts the literature that either suggests a positive impact (cf. inter alia Sweet 1998, 6ff.; Olbrich et al. 2012, 2) or no impact at all (cf. De Klerk 2004, 35). A possible explanation for the negatively affected ecosystem could be a more inattentive treatment of the rangeland when precipitation amounts are higher. Being exposed to scarce precipitation amounts, farmers might behave more prudent and cautious to avoid further degradation of the ecosystem. Thus, when rainfall is low, the awareness of the fragility of the ecological quality could rise and stimulate an ecologically adaptive treatment of the rangeland.

The application of financial risk management impacts positively on the ecological sustainability of the farm. When the importance for financial risk management is raised by one unit the actual bush cover decreases by 3.94%, compared to the optimal fraction of bush cover. This result contradicts findings of various researchers who identify a negative effect of financial risk management on the ecosystem quality, depending on the ecosystem's properties (cf.

Müller et al. 2011, 3; Quaas & Baumgärtner 2008, 14; Quaas & Baumgärtner 2009; Horowitz & Lichtenberg 1993). However, Di Falco et al. (2011, 7f.) and Lukomska et al. (2014, 27f.) support the positive relation between financial risk management as an insurance against risks and a positive development of the sustainability level on farm. As inadequate farm management is deemed to be one major reason for the degradation of the system (cf. Olbrich et al. 2014, 3), applying less financial risk management reduces ecological sustainability.

The rating of political risks, the dummy variable for continuing the farm business until retirement, the dummy variable for farm future as being handed on to the next generation after the farmer retires and the two separate on-farm management strategies for additional feed and spatial diversification show no significant impact on ecological sustainability.

A second regression model explicitly analyses the effect of risk management strategies on ecological sustainability. Besides all previously described predictors, the variables for on-farm risk management and collective risk management are added to the model. Although a significant impact of both variables was expected, no effect could be detected. As ecological strategies, on-farm risk management reacts on ecosystem dynamics by changing the production process (cf. Olbrich et al. 2009, 8). Because of adapting the impact on the ecosystem according to its condition, an improvement of the ecosystem quality seems reasonable. Table 34 shows the regression results when all three variables for risk management are included into the model.

4.2.2. Regression model for economic sustainability

The economic sustainability of the farm is determined by the farmer's level of education, his income level, the ownership structure and the farmer's risk preferences (see Fig.11). The exact regression results are given in Appendix D, in Table 35.

An increasing income from cattle farming impacts positively on economic sustainability. If the farming income increases by N$ 1 the deficit of actual income in relation to the desired income to sustain farming reduces by N$ 0.33. Improving the income-situation of the farmers will contribute to the economic sustainability of the farm.

Whereas the level of education shows a positive impact on ecological sustainability, it does not so for the economic sustainability. Instead, the level of education has a negative impact. For farmers, who enjoyed a higher education the economic sustainability is N$ -34,481.13

lower than for those farmers who obtained high school education at maximum. Though this influence sounds slightly odd at first sight, it might be attributed to the variable-definition of economic sustainability as a difference between actual income from farming and the level of sustainable income. A higher education might still increase the economic outcome of the farming business while at the same time increasing the expectations towards the income threshold to a stronger extent. A higher income combined with an even higher indication for a sustainability threshold to be reached, results in a negative effect on economic sustainability. A negative impact on economic sustainability is also found when the farmer owns his farm business. If the farmer is the owner of his farm the economic sustainability decreases by N$ -88,172.51 compared to foreign ownership, with the farmer being a hired manager or tenant of the farm. We find no obvious explanation for this direction of influence.

Risk preferences impact negatively on economic sustainability. If the farmer's risk preferences increase by one unit, i.e. he becomes more risk friendly, the gap between the present income situation and the indicated income threshold widens by N$ -10,687.8. A risk averse farmer will then choose a sustainable risk management strategy which increases the economic sustainability. This result conforms to various findings in the literature (cf. Lukomska et al. 2014, 23; Quaas et al. 2007, 251). Our results support the direct impact of risk preferences on sustainability. Hence, individual risk preferences directly affect the ability to sustain the livelihood of the farmer.

The rangeland size as a proxy for wealth, the dummy variable for living in an unfavourable region and the dummy variable for continuing the farm business until retirement show no significant impact on economic sustainability.

A second regression model explicitly analyses the effect of risk management strategies on economic sustainability. Besides all previously described predictors, the variables for on-farm, financial and collective risk management are added to the model. Although a significant impact of both variables was expected, no effect could be detected. Table 36 shows the regression results for this extended regression model.

4.3. Determinants for risk management

The following sections 4.3.1, 4.3.2 and 4.3.3 analyse the third research question and introduce the determinants for on-farm, financial and collective risk management. For each management variable it is also tested whether ecological and economic sustainability possess a significant impact. Which factors drive the application of risk management strategies? Is the importance of the applied risk management strategies mainly a result of exogenous factors or that of farm-individual characteristics?

Due to the incapability of constructing suitable instrument variables, the three risk management strategies cannot be estimated jointly in a simultaneous equation model[7] although all strategies are significantly interrelated (cf. Olbrich et al. 2014, 19). Therefore, the three management strategies are determined in separate regression equations without including the respective other management strategies.

4.3.1. Regression model for on-farm risk management

The application of on-farm risk management is determined by a constant, the farmer's education and gender, the rangeland size, various risks and the operation time on farm (see Fig.12). The exact regression results are given in Appendix D, in Table 37.

The significant constant term of 2.25 indicates that on-farm management strategies are of general importance and therefore a priori applied to a certain degree. Although their importance is not too strong in relation to the six-item Likert-scale within which management strategies are defined. Being educated in an ecological field of study further increases this value by 0.47 units. An ecological education supports the use of on-farm risk management to combat environmental and income risks. As on-farm risk management comprises ecological strategies it seems reasonable that an ecological education supports the use of on-farm risk management (cf. Olbrich et al. 2009, 8). In contrast to this, farmers who are educated in multiple fields of study show a negative relation to on-farm risk management. If a farmer enjoyed multiple educations, the importance of on-farm risk management diminishes by 0.77 units on the Likert-scale. A further decrease in on-farm risk management occurs if the farmer is male. The importance of on-farm risk management is 1.19 units lower for male farmers than for female farmers. Although Olbrich et al. (2011, 24f.) identify male farmers to be more risk averse, which might in turn lead to a higher valuation of risk management strategies, an impact of gender in both directions seems plausible (cf. Olbrich et al. 2014, 17). Additionally, male farmers impacting negatively on on-farm risk management conforms to more recent

[7] A simultaneous regression model predicts several dependent variables by a set of independent variables (cf. Timm 2002, 187) and allows an improvement in prediction accuracy (cf. Kohler & Kreuter 2001, 190).

findings, according to which female farmers show a positive effect on certain on-farm management strategies, namely resting rangeland and breed adaption (cf. Olbrich et al. 2014, 34).

An increase in rangeland size might increase the importance of risk management strategies, as Olbrich et al. (2014, 17) find out for their prediction of single on-farm management strategies for the same dataset. But generally both effects seem plausible, as other references show different results. A bigger size of the rangeland might increase the workload for applying risk management strategies which could have a deterrent effect and, thus, lower their relevance (cf. Yesuf & Bluffstone 2009, 1030f.). This effect, however, is not discernible for the analysed case study. Our results support the positive relation between rangeland size and on-farm risk management. If the rangeland increases by one ha the use of on-farm risk management increases by 4.65e-05 units.

An increasing relevance of natural, economic and political risks leads to an increased importance of on-farm risk management. If natural risks rise by one unit, measured on a six-item Likert-scale, counteracting these risks by applying on-farm risk management strategies rises by 0.29 units. With a 0.29 units increase, natural risks have the strongest impact on on-farm risk management compared to all other risks. If economic risks increase by one unit, the importance of on-farm risk management will increase by 0.20 units. If the relevance of political risks increases by one unit, on-farm risk management will increase by 0.22 units. Only the importance of other risks shows a negative relation to on-farm risk management. If other risks, like cattle theft or machine failure, increase by one unit, the importance of on-farm risk management will subside by 0.19. Here seems to be a trade-off between on-farm and collective risk management. While the relevance of on-farm risk management decreases with raising other risks, the relevance of collective risk management increases significantly (see 4.3.3).

The operation time is negatively related to on-farm risk management indicating a decreasing application of on-farm management strategies with increasing operation time on farm. With each year the farmer operates on his farm on-farm risk management is lesser applied by 0.01 units. While the farmer gains experience through operating his farm business on-farm risk management plays a shrinking role. Opposed to this effect, an increasing experience in farming leads to a positive impact on the other two variables for risk management; years of experience increases collective risk management and years of experience as farm-owner increases the use of financial risk management (see 4.3.2 and 4.3.3). As operation time and years of experience (Pearson: 0.8002, $p<0.0001$) and operation time and experience as owner (Pearson: 0.8006, $p<0.0001$) are highly correlated, a considerable similarity between the variables can be supposed. This picture, again, could indicate a trade-off between the three risk management variables concerning some sort of farming experience.

Risk and time preferences do not impact on on-farm risk management. Although especially risk preferences possess a certain explanatory power for the model (an increase in R^2 adj. of 4% and a decrease in the Akaike Information Criterion (AIC) of around 30), no significant impact of either risk or time preferences could be detected. In addition, the annual average precipitation and the dummy variable for the future of the farm, being handed on to the next generation after the farmer retires, show no significant impact on on-farm risk management.

A second regression model explicitly analyses the potential impact of sustainability on on-farm risk management. Besides all previously described predictors the variables for ecological and economic sustainability are added to the model. No significant effect could be detected. Table 38 shows the regression results for the inclusion of both sustainability variables into the model.

4.3.2. Regression model for financial risk management

The application of financial risk management is determined by the farmer's ethnic background, his education and experience, the amounts of precipitation, various risks and full-time farming (see Fig.13). The exact regression results are given in Appendix D, in Table 39.

Caucasian ethnicity decreases the application of financial risk management. This seems surprising. With the traditional background of indigenous farmers in mind, one would not expect them to value financial risk management higher than Caucasian farmers do. Yet, if farmers are of Caucasian ethnicity the importance of financial risk management is decreased by 1.15 units. This suggests that Caucasian farmers might be suspicious of financial management strategies and prefer to continue their usual farm management. As 95.41% of all farmers are of Caucasian ethnicity, a vast majority rarely chooses to apply financial risk management to diminish the implications of environmental risks (cf. Quaas & Baumgärtner 2008; Müller et al. 2011). Still, this result has to be interpreted carefully as indigenous farmers are undersampled in the case study (see 3.1).

If farmers are educated in a technical field of study, financial risk management becomes more important. For technically educated farmers financial risk management is 0.47 units higher than for farmer without any technical education. The amount of annual precipitation also shows a positive impact on the importance of financial risk management. If the average annual precipitation rises by 1 mm, the relevance of financial risk management rises by 2.49e-03 units. We can find no obvious explanation for this effect. Again, the amount of precipitation impacts in a direction other than expected. As a consequence, special attention is paid to this issue within the section of model validation in Section 5.6.

Natural and political risks both show a positive impact on financial risk management. If the relevance of natural risks increases by one unit, financial risk management rises by 0.29 units on the Likert-scale. If political risks rise by one unit, the importance of financial risk management rises by 0.22 units. Thus, increasing risks raise the importance to apply financial management strategies to counteract those risks. Financial risk management is also positively influenced by the farmer's years of experience as an owner. With each additional year of experience as an owner the relevance of financial risk management is increased by 0.02 units. Hence, the longer the farmer spends time on his farm as an owner, the more important financial risk management strategies become.

Full-time farming impacts negatively on financial risk management. If the farmer lives on his farm during the week, the relevance of financial risk management decreases by 0.41 units on the Likert-scale. As a result, part-time farmers rather apply financial risk management than full-time farmers do. Although full-time farmers are probably economically more dependent on the farm-business and could thus be more interested in risk management strategies, financial insurance obviously plays a smaller role for them.

Ecological and economic sustainability do not impact on financial risk management. Although both sustainability variables possess some minor fraction of explanatory power for the model, they do not impact significantly on financial risk management.

Economic education and economic risks do not impact on financial risk management. This indicates that the use of financial risk management strategies is not a response to economic risks but rather driven by socio-demographic aspects like ethnicity. In addition, the dummy variable for single ownership structure of the farm shows no significant impact on financial risk management.

4.3.3. Regression model for collective risk management

The application of collective risk management is determined by the future of the farm, the farmer's experience, his risk preferences and risks (see Fig.14). The exact regression results are given in Appendix D, in Table 40.

Other risks like cattle theft and machine failure impact positively on collective risk management. If the relevance of other risks increases by one unit, collective risk management will rise by 0.33 units. This effect seems reasonable as increasing risks support the need to combat those risks e.g. by applying risk management strategies. Another positive impact on collective risk management is detected if the farm is passed on to family members after the present farmer retires. If the farm is inherited by the family after the retirement of the present farmer, the importance of collective risk management increases by 0.96 units. When the farm is inherited by the farmer's family collective risk management is positively influenced compared to a situation where the farm is being dissolved or deteriorates after the farmer retires. This shows that a continuation of the farm business by the family enhances the incentive for involving into collective management and maybe engaging within communities - as opposed to the prospect of deterioration after retirement.

Risk preferences are negatively related to collective risk management. With increasing risk preferences farmers become more risk friendly and the use of collective risk management decreases. If risk preferences rise by one unit, collective risk management diminishes by 0.10 units. This indicates that a risk friendly farmer rather refuses to rely on collective strategies like governmental support and local and national interest groups that jointly address risks. Risk friendlier farmers are less affected by risks and if they feel the need to counteract these risks, they will probably manage the situation individually.

Lastly, collective risk management is positively influenced by the farmer's years of experience. With each additional year of experience as an owner, hired manager or in any other function on farm, the relevance of collective risk management is increased by 0.03 units. Hence, the longer the farmer spends time on his farm, the more important collective risk management strategies become.

Ecological and economic sustainability do not impact on collective risk management. Although both sustainability variables possess some minor fraction of explanatory power for the model, they do not impact significantly on collective risk management.

Time preferences do not impact on collective risk management. Still, they do hold a certain explanatory power for the model but no significant effect on collective risk management could be detected. In addition, multiple educations, the coefficient of variation in precipitation, political risks and the farmer's operation time on farm show no significant impact on collective risk management.

5. Model validation and robustness

This section evaluates the statistical validity of the above presented regression models. Sections 5.1 and 5.2 summarize model validity for ecological and economic sustainability and Sections 5.3, 5.4 and 5.5 describe model validity for on-farm, financial and collective risk management. All models are analysed with respect to goodness of fit, model robustness, functional form of the model and validity tests considering the model assumptions. Compliance with the model assumptions is essential for the coefficients to be efficient and unbiased (cf. Kohler & Kreuter 2001, 198). All regression models are conducted as linear models based on the ordinary least squares (OLS) method, where the regression is calculated with the residuals. The tested model assumptions for the OLS models refer to Wooldridge (2006, 89-129). In addition, the models for ecological and economic sustainability are compared to a Tobit model for right-censored variables, allowing for the distinctive feature that both variables are censored at zero (cf. Maddala 1983, 151ff.). The regression models for on-farm, financial and collective risk management are compared to an ordered Probit and an ordered Logit model for ordinal ranked dependent variables to account for their elicitation on a Likert-scale. Furthermore, structural validity and coefficient robustness are tested for all models by modifying the regression specification through adding or removing predictors. Special issues of model validity are addressed in Section 5.6, testing unexpected results and assuring the (in-)significance of certain predictors.

5.1. Model robustness and validation of ecological sustainability

The final model for ecological sustainability possesses an R^2 of 42.25%, which is the proportion of explained variability by the regression (cf. Frees 1996, 83). Considering the number of predictors, the adjusted R^2 reduces to 34.09%. Another measure of the explanatory power of the model is provided by the Akaike Information Criterion (AIC) and Schwarz's Bayesian Information Criterion (BIC) (Akaike 1974; Schwarz 1978). The AIC for the final regression model under OLS is 859.60 and the BIC is 896.88. AIC and BIC are measures used for the comparison of regression models. In case the two information criteria suggest different models, more importance is attached to the AIC in accordance with Burnham & Anderson (2004).

To make sure an adequate choice of regression model was made, a robust regression is conducted (cf. Li 1985; Olbrich et al. 2014, 24). As the impact of all predictors does not change their significance, the final regression model for ecological sustainability produces a robust result. Censored variables, like ecological sustainability, possess a large fraction of observations at the upper or lower limit. To account for this characteristic, the regression model is compared with a Tobit model[8] for right-censored dependent variables, with $Y=0$, when $y \geq y^*$ and $Y=y^*$, when $y < 0$. A similar picture arises with respect to the predictors when the regression is conducted in a Tobit model. The values for AIC and BIC are slightly smaller under a Tobit regression than under OLS. But the regression result for a Tobit model is not robust. Due to this fact, the similar results of both models and the numerous recognized test statistics to validate and assure the significance of an OLS regression, OLS was preferred to Tobit.

Ramsey's RESET test for omitted variables is conducted to avoid underspecification of the model (Ramsey 1969). According to Ramsey's RESET test $F=0.10$, with $p=0.9598$, the model shows no indication of omitted variable bias. Thus, a fatal underspecification of the model by omitting relevant variables can be neglected (cf. Wooldridge 2006, 95).

The existence of multicollinearity is tested by using the variance inflation factor (VIF). The VIF tests for significant correlations of the predictor variables and serves as an indicator for multicollinearity. A VIF larger than five indicates serious multicollinearity and violates the OLS assumption that there is no linear correlation between the independent variables (cf. Wooldridge 2006, 90f.). As a consequence, variables possessing a too high variance inflation factor should be excluded from the model. The final regression model for ecological sustainability possesses a VIF of 1.42. This result is considered satisfactory, as a VIF of one is the optimum.

The assumptions of the OLS model require the residuals to be randomly distributed and not to possess any information. The error term should not have any systematic influence on the expected Y. Therefore, the value of the residuals should be equal to zero: $E(\varepsilon)=0$ (cf. Wooldridge 2006, 92f.). The expected value of residuals is approximately equal to zero -

[8] The Tobit regression model holds the same assumptions as the classical linear model but with the particularity that it is specified for a latent variable which is censored (cf. Wooldridge 2006, 595ff.). Functional form: $y^* = \beta 0 + x\beta + u$, $u|x \sim \text{Normal}(0,\sigma^2)$ (cf. Wooldridge 2009, 594ff.).

1.52e-08. For standardized residuals the mean value is approximately zero (-1.33e-03) and the variance is approximately one (1.01). This also applies to studentized residuals (mean: -2.00e-03; variance: 1.04). Hence, the model complies with this OLS assumption.

A further assumption covers the issue of homoskedasticity. The variances of the residuals should be constant and equal: $Cov(\varepsilon_i)=\sigma^2 I_n$. And there should not be any correlation between the independent variables and the residuals: Cov(xi,εi)=0 (cf. Wooldridge 2006, 100). The existence of heteroskedasticity does not result in biased estimators but OLS estimates are no longer the best linear unbiased estimators (BLUE) because they do not provide estimates with the smallest variance (cf. Wooldridge 2006, 108f.). Thus, with heteroskedasticity the OLS-method would not generate efficient estimates. A homoskedasticity diagnosis is conducted with tests from White, Breusch-Pagan and Cook-Weisberg (White 1980; Breusch & Pagan 1979, Cook & Weisberg 1983). For the final model for ecological sustainability homoskedasticity can be assumed. White's estimator maintains H_0 "constant variance" with a Chi² of 95.51 and p=0.3256. According to Breusch-Pagan/Cook-Weisberg's F-test for the right-hand side, homoskedasticity can be assumed on a 5%-significance level (or higher) with F=1.64 and p=0.0893.

The residuals of the regression model should be normally distributed (cf. Wooldridge 2006, 123f.). The normality of residuals is tested by a Shapiro-Wilk's-test and by a Jarque-Bera-test, which considers the skewness and kurtosis of the distribution (Shapiro & Wilk 1965; Jarque & Bera 1987). Based on Jarque-Bera's Chi² of 0.56 with p=0.7544 and Shapiro-Wilk's z of -0.465 with p=0.67898, the residuals of the regression for ecological sustainability are normally distributed. Tests of the standardized residuals (Chi²=0.80 with p=0.6687, z=-0.279 with p=0.60982) and studentized residuals (Chi²=1.22 with p=0.5437, z=-0.081 with p=0.53209) confirm the normal distribution.

Outliers can modify and distort results significantly. Based on the Cook's distance measure outliers can be detected (Cook 1977). Observations with a too large Cook's distance are excluded according to their leverage $d=\frac{(2*k+2)}{n}$, with *k* being the number of predictors in the model and *n* the number of observations. For the regression model of ecological sustainability no outliers are identified by Cook's d.

The second regression model for ecological sustainability includes all three variables for risk management. The overall model fit is described by an R² adj. of 33.75%, an AIC of 861.80

and a BIC of 904.42. Ramsey's RESET test does not indicate any omitted variables (F=0.06 with p=0.9826) and multicollinearity is not an issue (VIF=1.71). Due to robustness of the OLS model, in contrast to the Tobit model, OLS was preferred to Tobit. The expected value of the residuals is equal to zero and both White's (p=0.4543) and Breusch-Pagan/Cook-Weisberg's estimators (p=0.1363) assume homoskedasticity. According to Jarque-Bera's Chi² (with p=0.7342) and Shapiro-Wilk's z (with p=0.54675) the residuals of the regression model are normally distributed. Lastly, no outliers could be detected by Cook's distance measure.

5.2. Model robustness and validation of economic sustainability

The (pre-)final model for economic sustainability possesses an R^2 of 12.52% and an adjusted R^2 of 10.02%. Due to the poorness of the model-fit, the constant was omitted in the model. Without the constant the explanatory power of the model rises to 60.92% for R^2 and 59.81% for R^2 adj. As a consequence of omitting the constant from the model, certain statistical tests become invalid because of their limited application to OLS-models with constant term. That is the Ramsey RESET test for omitted variables, all Breusch-Pagan/Cook-Weisberg-tests for heteroskedasticity and the robust regression. As a result, all test statistics are conducted for the final model with constant and - whenever possible - for the final model without constant.

Both, the Akaike Information Criterion with 6,658.32 and Schwarz's Bayesian Information Criterion with 6,683.05, are slightly better for the model without constant compared to the same model with constant (AIC: 6,660.32 and BIC: 6,688.58).

For the model comprising the constant, a robust regression is conducted. As the impact of all predictors does not change their significance the regression model produces a robust result. The model then is compared to a Tobit model for right-censored dependent variables. A similar picture arises with respect to the predictors when the regression is conducted in a Tobit model. In addition, the Tobit model also produces a robust regression result. Although the values for AIC and BIC are smaller under a Tobit regression than under both OLS models, the OLS regression model without constant term is preferred to the Tobit model. This is attributed to a variety of reasons. The Tobit model is much more vulnerable to a violation of model assumptions, especially concerning the distributions of the error terms. Due to the non-normal distributed error terms (see below for proof) heteroskedasticity will likely be a major problem for the regression model. Unfortunately, there are no tests to check for heteroskedasticity for a

Tobit model available in Stata.[9] With existing heteroskedasticity the Tobit coefficient is badly biased (cf. Maddala 1983, 149ff.). Yet, for an OLS regression numerous recognized tests statistics exist to validate the results of the model. The main focus of this regression model is to estimate valid regression results. Due to this fact, the sensitivity of a Tobit model towards a violation of assumptions and the recognized test statistics to validate the OLS regression, the OLS model is preferred to Tobit. In addition, an OLS regression yields the great advantage of direct interpretation of the estimated coefficients.

The Ramsey's RESET test for omitted variables is conducted to avoid underspecification of the model. According to its test-statistics the model shows no indication of omitted variable bias ($F=1.89$ with $p=0.1314$). This test, unfortunately, is only conductible for the regression model with constant term.

The variance inflation factor for the model with constant term yields a very low value, with a VIF of 1.09 compared to the optimal VIF of 1. For the regression model without constant an uncentered VIF was applied. This modified variance inflation factor detects collinearity of the predictors with the constant and can thus be used when omitting the constant in the model. The uncentered VIF amounts to 4.86. This value is considerably higher than the VIF for the previous model but still below 5 (limit for multicollinearity).

The assumptions of the OLS model require the residuals to be randomly distributed and not to possess any information. For the model including the constant, the expected value of (standardized) residuals is approximately equal to zero (-5.07e-04) and the variance is approximately one (1.001). For studentized residuals the mean value is also approximately zero (-3.06e-03) and the variance is approximately one (1.02). This result is reflected in the analysis for the regression model without constant: standardized residuals possess an expected value of 1.19e-04 and a variance of 1.002; studentized residuals have an expected value of -2.43e-03 and a variance of 1.02. Hence, the model complies with this OLS assumption.

To generate efficient estimates, homoskedasticity is an underlying assumption of the OLS model. A homoskedasticity diagnosis for the model with constant is conducted with the White estimator and a Breusch-Pagan/Cook-Weisberg F-test for the right-hand side of the equation. White's estimator maintains H_0 with a Chi^2 of 26.54 and $p=0.6950$. Breusch-Pagan/Cook-

[9] In the basic package for Stata 12 no test-statistics are available. There are, however, additional Stata-packages that include tests on heteroskedasticity for Tobit models. Unfortunately, it wasn't possible to gain access to these additional packages.

Weisberg's F-test for the right-hand side yield a result of F=1.20 and p=0.3044. For the final model without constant only the White-test is applicable. With Chi² 26.58 and p=0.6933 it confirms the previous results that heteroskedasticity can be rejected and homoskedasticity can be assumed for the regression model for economic sustainability.

Besides having a constant variance, the residuals of the regression model should be normally distributed. However, when testing the residuals of the regression model with constant (without constant) based on Jarque-Bera's Chi² of 42.15 (42.24), p=0.0000 (p=0.000) and Shapiro-Wilk's z of 6.468 (6.477), p=0.0000 (p=0.000) the residuals of the regression model are non-normally distributed. The same picture arises when testing the standardized residuals: Chi²=42.05 (42.23), p=0.0000 (p=0.0000) and z=6.469 (6.479), p=0.0000 (p=0.0000) or the studentized residuals: Chi²=44.61 (44.79) with p=0.0000 (p=0.0000) and z=6.542 (6.552), p=0.0000 (p=0.0000). No transformation[10] of variables (dependent or independent) evokes a change in the above test-statistics. The p-value always remained < 0.0001. As a consequence of the non-normality of residuals, the OLS estimates are no longer BLUE (cf. Vinod & Ullah 1981, 2ff.). The estimators remain linear and unbiased but without the assumption of a normally distributed error term the OLS regression no longer has the smallest variance (cf. Wooldridge 2006, 124). As a result, the F- and t-test-statistics of the regression model have to be treated with extreme caution as they might no longer produce valid results (cf. Hill et al. 2008, 89).

Finally, based on the Cook's distance measure one outlier could be detected. All observations from the questionnaire no.134 ae omitted in the regression model for economic sustainability due to a Cook's d of 0.0806384. Any other extreme outliers within each variable were omitted beforehand.

The second regression model for economic sustainability includes all three variables for risk management. As this is not the final regression model and primarily serves at demonstrating the impact of risk management on economic sustainability, the constant term is not omitted. This allows for the conduction of more test statistics to assure model validity. Consequently, the explanatory power of the model is not the predominant objective but rather the creation of valid results for the impact of the predictor variables on the latent variable. The overall model fit of this second regression is thus quite low with an R² adj. of only 10.14%, an AIC of

[10] Based on the "ladder of powers" the following transformations were conducted, if promising: cubic, square, square root, log, 1/(square root), inverse, 1/square and 1/cubic.

6,500.93 and a BIC of 6,539.48. Ramsey's RESET test does not indicate any omitted variables (F=2.12 with p=0.0989), as long as a significance level of at least 5% is required to reject H_0. With a VIF of 1.16, multicollinearity does not exist between the predictors of the model. Both, OLS and Tobit model, produce robust results. As to the extensive possibilities for model validation, OLS is preferred to a Tobit model.

The expected value of the residuals is equal to zero and both White's (p=0.5766) and Breusch-Pagan/Cook-Weisberg's estimators (p=0.1646) assume homoskedasticity. According to Jarque-Bera's Chi² (with p=0.0000) and Shapiro-Wilk's z (with p=0.0000) the residuals of the regression model are not normally distributed. As previously explained, the reader is advised to be cautious when interpreting the results of the regression model. Lastly, no outliers could be detected by Cook's distance measure.

5.3. Model robustness and validation of on-farm risk management

The final model for on-farm risk management possesses an R^2 of 37.62% and an adjusted R^2 of 29.82%. The relative quality of the regression model is represented by an AIC of 277.77 and a BIC of 316.56 for the regression model under OLS. This regression model produces a robust result, as no change in significance for any variable occurs. The regression model then is compared with an ordered Probit model.[11] The ordered Probit model produces the same robust results as an OLS model. But the values for AIC and BIC of the ordered Probit model strongly suggest an OLS regression (AIC: 726.20 and BIC: 834.26). The final regression model is also compared to an ordered Logit model.[12] The same results come up when an ordered Logit regression is conducted. While the ordered Logit regression also yields a robust regression result, the values for AIC and BIC support as well the use of an OLS model (AIC: 728.57 and BIC: 836.62). Hence, the OLS regression model is preferred to both ordered models.

According to Ramsey's RESET test with F=0.21 and p=0.8908, the model shows no indication of omitted variable bias. Also, the variance inflation factor to detect multicollinearity is satisfyingly low for the final regression model, with a VIF of 1.38. The expected value of the residuals is approximately equal to zero, with -1.70e-09. For standardized residuals the mean

[11] The ordered Probit model is specified for an ordered response variable and has the functional form: $P(y=0|x) = P(y^* \leq \alpha_1|x) = P(x\beta + e \leq \alpha_1|x) = \Phi(\alpha_1 - x\beta)$, $P(y=1|x) = P(_{\alpha 1} < y^* \leq \alpha_2|x) = \Phi(\alpha_2 - x\beta) - \Phi(\alpha_1 - x\beta)$, …, $P(y=J|x) = P(y^* > \alpha_J|x) = 1 - \Phi(\alpha_J - x\beta)$ (cf. Wooldridge 2009, 504f.).

[12] The ordered Logit is as well specified for an ordered response variable y and is defined by the functional form of the ordered Probit model, when Φ is replaced by the logit function Λ (cf. Wooldridge 2009, 505).

value is approximately zero (-2.39e-03) and the variance is approximately one (1.005). This applies also to studentized residuals (mean: -2.69e-03; variance: 1.02). When testing for heteroskedasticity all test measures assume homoskedasticity. White's estimator maintains H_0 with a Chi² of 81.19 and p=0.5359 and the classical Breusch-Pagan/Cook-Weisberg-test maintains H_0 with a Chi² = 0.24 and a corresponding p=0.6231. In addition, both F-tests from Breusch-Pagan/Cook-Weisberg support the existence of homoskedasticity: their F-test for the whole regression equation with F=0.28 and p=0.5956 and their F-test for the right-hand side with F=0.88 and p=0.5776.

The OLS requirement of a normal distribution of residuals is fulfilled by the model. Based on Jarque-Bera's Chi² of 0.36 with p=0.8348 and Shapiro-Wilk's z of -0.943 with p=0.82705, the residuals of the regression for on-farm risk management are normally distributed. Tests of the standardized residuals (Chi²=0.57 with p=0.7526, z=-0.757 with p=0.77546) and studentized residuals (Chi²=0.30 with p=0.8595, z=-0.918 with p=0.82076) confirm the normal distribution. With the Cook's distance measure no outliers could be detected.

The second regression model for on-farm risk management includes both variables for sustainability. The overall model fit is described by an R² adj. of 29.06%, which is slightly smaller the R² adj. for the previously described final regression model. When including the sustainability variables in the model the variables for economic, political and other risks become insignificant (see Tab.38). All other variables do not change significance compared the final model without sustainability. The regression model produces a robust result. However, both sustainability variables show no significant impact on on-farm risk management. Excluding the three risk-variables does not change the insignificance of both sustainability variables, but reduces the model fit and yields a non-robust equation. Although not significant within this particular regression model, the three risk-variables stay within the model.

Both AIC and BIC are with 196.32 and 236.14 considerably lower than the information criteria for the same equation in an ordered Probit model (AIC: 536.44 and BIC: 628.52) and an ordered Logit model (AIC: 540.42 and BIC: 632.50). This comparison strongly suggests the use of and OLS model for the regression model including sustainability. Ramsey's RESET test does not indicate any omitted variables (F=0.97 with p=0.4135) and multicollinearity is not an issue (VIF=1.50). The expected value of the residuals is approximately equal to zero and White's test (p=0.4501) as well as Breusch-Pagan/Cook-Weisberg's classical (p=0.7089) and F-test estimators (for the whole equation with p=0.6476 and for the right-hand side with p=0.8368) assume homoskedasticity. According to Jarque-Bera's Chi² (with p=0.1974) and Shapiro-Wilk's z (with p=0.49445) the residuals of the regression model are normally distributed. Lastly, no outliers could be detected by Cook's distance measure.

5.4. Model robustness and validation of financial risk management

The final model for financial risk management possesses an R^2 of 46.07% and an adjusted R^2 of 40.03% which demonstrates a good explanatory power of the model. The relative quality of the regression model is represented by an AIC of 340.04 and a BIC of 378.19 for the regression model under OLS. As no change in significance for any variable could be detected under the robust regression, the regression model is deemed robust. The model then is compared with an ordered Probit and an ordered Logit model. The latter two models yield similar results like the OLS regression and the significances do not change under robust regression. Owing to the considerably high values for AIC and BIC, the OLS model is preferred to the ordered models. The ordered Probit model entails an AIC of 903.00 and a BIC of 1035.05. The ordered Logit model conducts an AIC of 904.02 and a BIC of 1036.07.

According to Ramsey's RESET test with F=1.32 and p=0.2708, the model shows no indication of omitted variable bias. Also, the variance inflation factor to detect multicollinearity is satisfyingly low for the final regression model, with a VIF of 1.25. When omitting the constant term in the model (as it shows no significance) the adjusted R^2 reaches over 95% but the uncentered VIF explodes to 14.60. This indicates serious multicollinearity issues. As a consequence, the constant term stays within the model.

The expected value of the residuals is approximately equal to zero, with -1.27e-09. For standardized residuals the mean value is approximately zero (2.09e-03) and the variance is approximately one (1.01). This applies also to studentized residuals (mean: 1.34e-03; variance: 1.02). When testing for heteroskedasticity all test measures assume homoskedasticity. White's estimator maintains H_0 with a Chi² of 72.25 and p=0.6319 and the classical Breusch-Pagan/Cook-Weisberg-test maintains H_0 with Chi²=0.00 and p=0.9539. In addition, both F-tests from Breusch-Pagan/Cook-Weisberg support the existence of homoskedasticity. Their F-test for the whole regression equation with F=0.00 and p=0.9522 and their F-test for the right-hand side with F=1.07 and p=0.3907.

The residuals of the final regression model for financial risk management are normally distributed. This is documented by Jarque-Bera's Chi² of 1.20 with p=0.5477 and Shapiro-Wilk's z of -0.422 with p=0.66356. In accordance with the latter results, tests of the standardized residuals (Chi^2=0.99 with p=0.6087, z=-0.362 with p=0.64127) and studentized residuals (Chi^2=0.96 with p=0.6191, z=-0.415 with p=0.66106) confirm the normal distribution. Based on Cook's distance measure one outlier could be detected. With a Cook's d of 0.0974971, the observations from questionnaire no.56 are omitted.

5.5. Model robustness and validation of collective risk management

The final model for collective risk management possesses an R^2 of 35.34% and an adjusted R^2 of 25.86%. The relative quality of the regression model is represented by an AIC of 213.98 and a BIC of 243.57 for the regression model under OLS. No change in significance of the predictors could be detected under robust regression. The regression model is compared with an ordered Probit and an ordered Logit model. Both, Probit and Logit model, lead to a similar regression result and pass the significance-test under robust regression. The ordered Probit model yields an AIC of 409.27 and a BIC of 468.45. The ordered Logit model conducts an AIC of 412.61 and a BIC of 471.80. Owing to its considerably lower values concerning the information criteria, the OLS model is chosen as the final regression model.

According to Ramsey's RESET test with F=0.92 and p=0.4345, the model shows no indication of omitted variable bias. With a VIF of 1.44, the variance inflation factor to detect multicollinearity is satisfyingly low for the final regression model. When the insignificant constant term is omitted in the model the adjusted R^2 reaches over 96% but the uncentered VIF of 16.74 indicates serious multicollinearity issues. To avoid the issue of multicollinearity the constant term stays within the model.

The expected value of the residuals is approximately equal to zero, with -1.80e-09. For standardized residuals the mean value is approximately zero (1.42e-03) and the variance is approximately one (1.02). This applies also to studentized residuals showing a mean of -4.95e-04 and a variance of 1.05. In addition, the regression model fulfils the assumption for homoskedasticity. White's estimator maintains H_0 with a Chi^2 of 72.30 and p=0.3694 and Breusch-Pagan/Cook-Weisberg's F-test for the right-hand side maintains H_0 with an F of 1.36 and p=0.2111.

The residuals of the final regression model for collective risk management are normally distributed. This is documented by Jarque-Bera's Chi^2 of 1.93 with p=0.3812 and Shapiro-Wilk's z of 0.076 with p=0.46959. In accordance with these results, the tests of standardized residuals (Chi^2=1.50 with p=0.4728, z=-0.246 with p=0.59704) and studentized residuals (Chi^2=1.45 with p=0.4832, z=-0.317 with p=0.62422) confirm the normal distribution. Based on Cook's distance measure no outliers could be detected.

5.6. Further validation of regression models

In addition to the previously described validity tests, further tests are conducted concerning the specification of income, precipitation data and risk management.

To account for the non-detailed elicitation of the income variable in limited intervals, different income definitions were conducted. Instead of using the mid-points of the income intervals we took the upper bound of each income interval (for total income and income from farming) for a first robustness check and the lower bound of the intervals for a second robustness check (cf. Olbrich et al. 2014, 24). As a third robustness check the variable for total annual income was inserted instead of the variable for income from farming. The first two checks confirm the results of the initial income variable as no changes in significance could be detected through any of the two modifications. With the third robustness check the income variable becomes insignificant for the model including this variable. For all other variables within the regression model no change in significance occurs and none of the three risk management strategies show an impact on economic sustainability.

Owing to the surprising results of the precipitation data (see 4.2.1 and 4.3.2) the variables were transformed with respect to their elicitation period. A lower average precipitation and a higher coefficient of variability in precipitation were expected to negatively impact on sustainability and favour the application of management strategies. But instead the coefficient of precipitation variation has no influence on any of the dependent variables and a rising average precipitation decreases sustainability and increases management strategies. To check for the robustness of this result the considered data period for the precipitation variables was limited to the operational time period each farmer had indicated, instead of using the whole period of REMO data availability. By this transformation, only those precipitation amounts are included in the variables that the farmer himself experienced and reacted to. Still, no differences in any in the regression coefficients could be observed.

Finally, the variables for risk management were specified differently. As the literature strongly suggests the influence of all three management strategies, but only financial risk management showed a significant impact, variable transformations are conducted to assure the presented results (cf. Olbrich et al. 2014, 7). Firstly, all on-farm management strategies are as well considered separately in the model, as Olbrich et al. (2014, 12) consider these strategies as determining factors to predict sustainability norms, but again, no significant influence can be observed. In addition, all three variables were transformed to dummies indicating the rating of a management strategy as either important (value > 3 on the six-item Likert-scale) or unimportant (value ≤ 3). As especially on-farm risk management is expected to have a strong connection to sustainability, a further transformation was conducted by constructing a dummy variable indicating that only on-farm risk management is important or not: on-farm risk management is not important or at least one other variable for risk management is important. None of the above shown variable modifications leads to change in significance. Thus, our results find no evidence for the influence of on-farm and collective risk management on sustainability and none for financial risk management on economic sustainability.

6. Discussion and conclusion

In the tightly coupled system in which cattle farmers in Namibia act it is of essential relevance that certain risk management strategies, while being substitutes in their ability to reduce risks, are of substantial difference regarding their impact on sustainability (cf. Müller et al. 2011; Olbrich et al. 2009). In accordance with that, De Klerk (2004) points out that the use of inadequate management strategies is one distinct reason for the degradation of semi-arid rangelands. Because risk management strategies are modifiable parameters, farmers can influence them to cope with specific challenges they encounter within this coupled ecosystem. This aspect underlines their relevance when thinking about the design of potential policies. Eventually, when thoroughly understanding the determinants of risk management strategies and their impact on the ecosystem and economic welfare of the farmers, this bears the potential to enhance the ecosystem quality by political means. There is a need for research on potential incentives or stimulation instruments for those factors that promote a sustainable development of the ecosystem.

With our work we try to assess risk management strategies and the sustainability of the coupled ecological-economic system to ultimately contribute to an understanding of how political and economic instruments and institutions have to be designed to promote the sustainable use of this ecosystem (cf. Olbrich et al. 2009, 3; Olbrich et al. 2012, 21).

However, our analyses yield the result that only financial risk management strategies are significantly impacting on the condition of the ecosystem. This is partly contradictory to the findings of Olbrich et al. who suggest (at least) on-farm management strategies to have strong influences on the ecological rangeland condition. Our work, in contrast, rather exposes the necessity to design an incentive scheme for applying more financial management strategies, as they promote the sustainability of the ecosystem.

Following our results, financial risk management strategies are ecological-economically adaptive management strategies as they are favouring the ecosystem condition on the farm and promote a sustainable development of the ecosystem. The negative impact on financial risk management by a vast majority of farmers, particularly Caucasian farmers, indicates an underrating of the potential of these strategies. Besides their positive impact on ecological sustainability the use of a financial insurance can reduce income risks affecting the farmers. Our work reveals the need for further research and in-depth analyses on the effect of financial risk management of commercial cattle farmers within the investigated area. It might make sense to conduct a second analysis focusing on the individual financial risk management strategies. Because of the heterogeneous rating of those strategies across farmers (cf. Olbrich et al. 2012, 13) the separate analysis of financial management strategies with respect to their determinants and their impact on ecological sustainability could yield some valuable results.

Considering the determinants of the aggregate risk management strategies, the results suggest some sort of trade-off between the three risk management variables with rising farming experience. With increasing operation time on farm the relevance of on-farm risk management strategies is further diminished. As opposed to this, financial and collective risk management are increasingly applied the more experience the farmer gains. Experience thus does not diminish the importance of risk management strategies in general; it only favours a trade-off between the three variables.

When looking at risk preferences, our work bears some surprising results. Individual risk perceptions directly impact on economic sustainability and thus influence the farmer’s ability to sustain his livelihood and that of future generations. More risk averse farmers show a better economic sustainability and stronger rely on collective risk management through governmental assistance or interest groups. It is however surprising that risk preferences do not influence the ecosystem condition although literature suggests a strong connection (cf. Quaas et al. 2007, 252). In addition, Quaas et al. (2007) state that a risk averse farmer will choose a management strategy that favours insurance from the ecosystem. Opposed to this, our analyses show no indication of risk preferences impacting on on-farm risk management.

After all, some results do not reveal a clear picture and should thus be viewed in the light of the specific context of commercial cattle farming in Namibia. A weakness of the conducted analyses could be related to the regression model for economic sustainability. Surprising results like the negative impacts of education and ownership on economic sustainability may be attributed to the construction of the variable for economic sustainability. Although the variable was validated with several correlation analyses, there still might be some weakness concerning the income threshold each farmer indicated individually. It seems possible that some farmers indicated personally desired income levels that are not based upon the annually needed levels to be able to sustain cattle farming also for future generations.

In conclusion, the conducted analyses provide some interesting results that sometimes cannot be thoroughly explained and related to the literature. In the end, the high return rates of the survey (see 2.1) show the importance of the present analysis to cattle farmers in Namibia. This fact together with the results of the analyses reinforces the need for further research.

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Appendix A: Descriptive statistics, figures

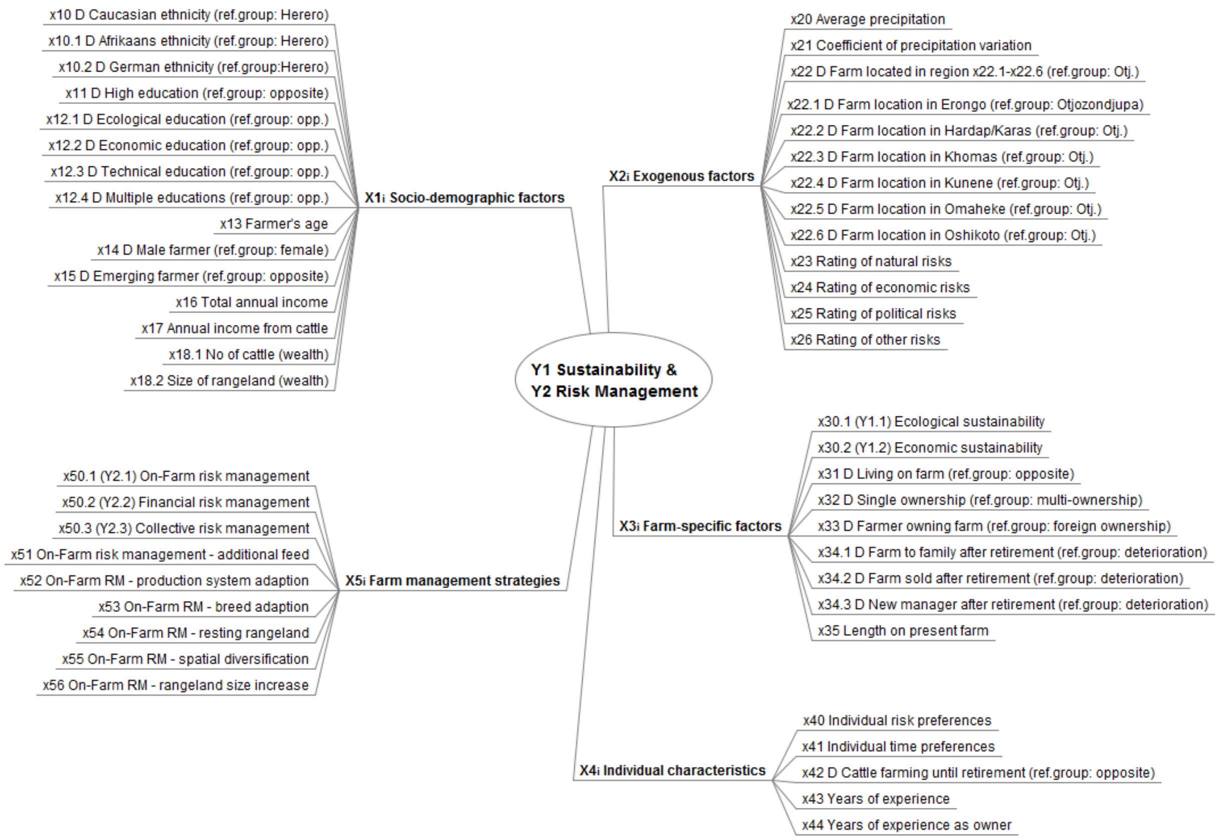

Figure 1: Initial list of variables to determine sustainability and risk management
A 'D' before the variable name indicates the construction as dummy variable.

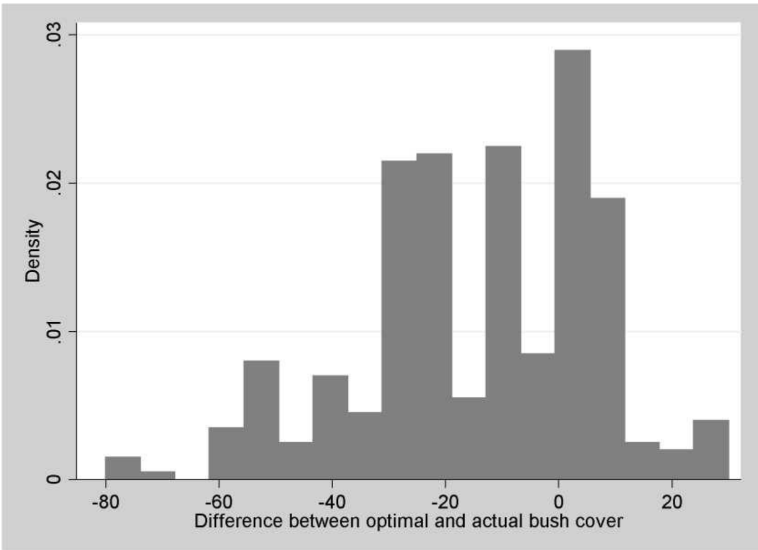

Figure 2: Difference between threshold level for sustainability and actual bush cover (in %)

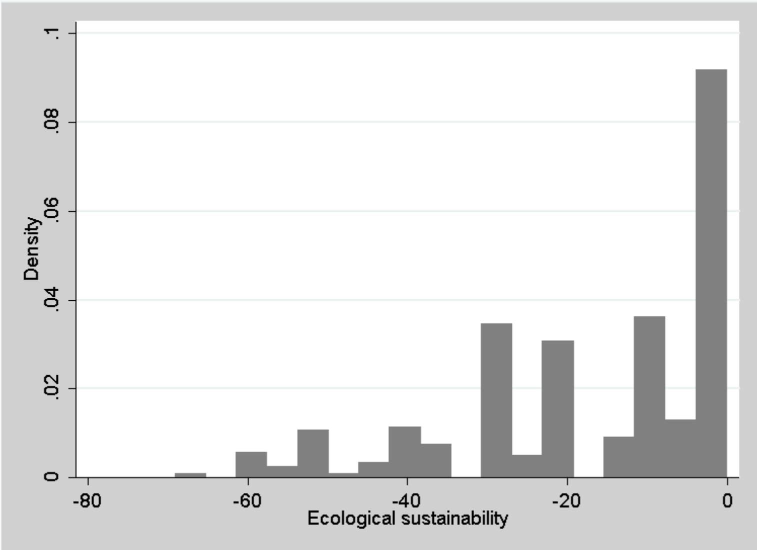

Figure 3: Histogram for the censored variable for ecological sustainability (in %)

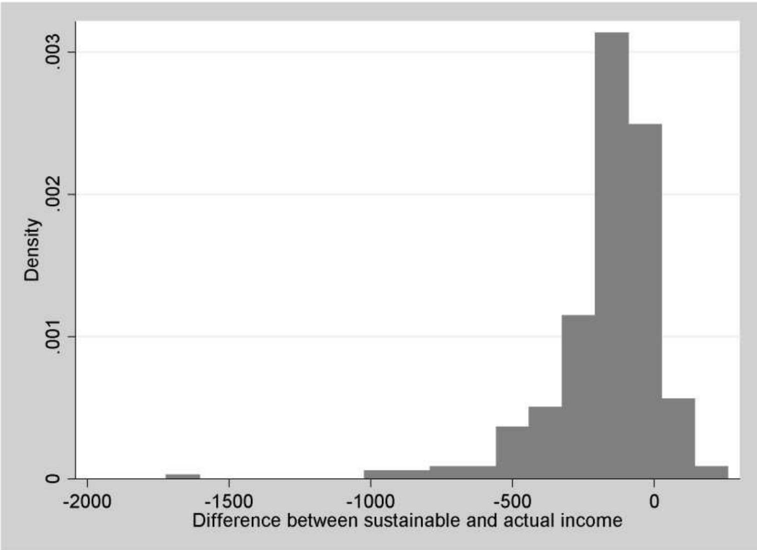

Figure 4: Difference between sustainable income threshold and actual income (in N$ 1,000)

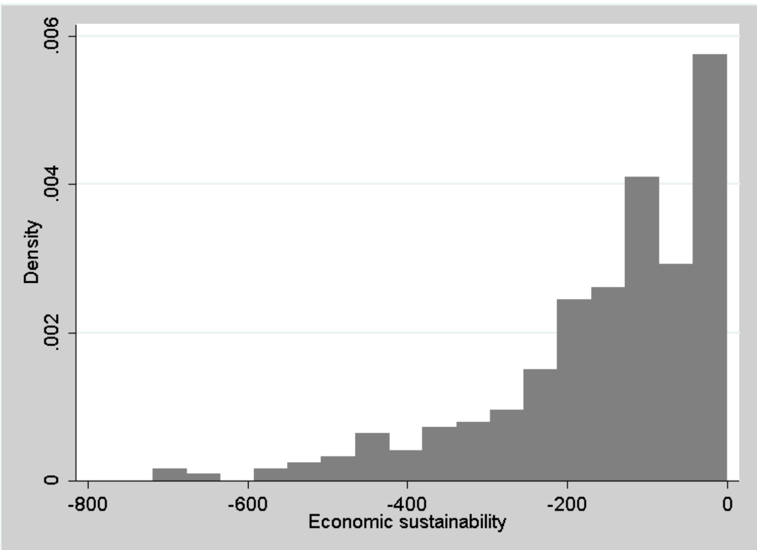

Figure 5: Histogram for the censored variable for economic sustainability (in N$ 1,000)

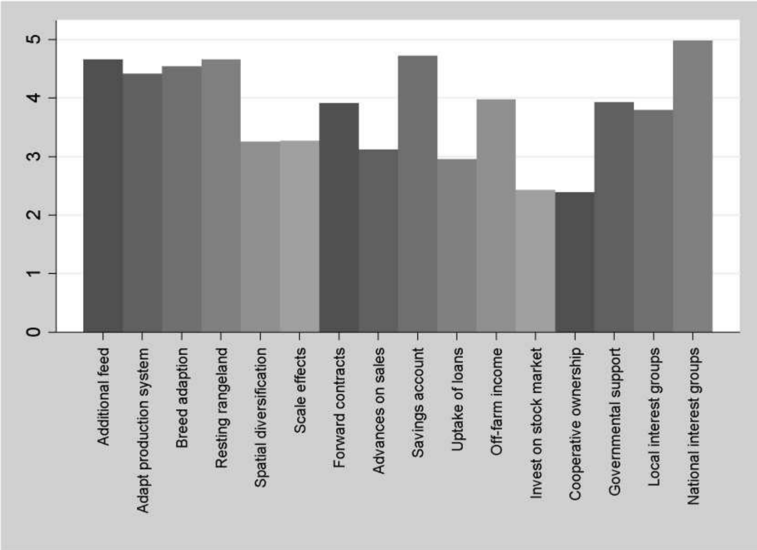

Figure 6: Average importance of all risk management strategies in comparison

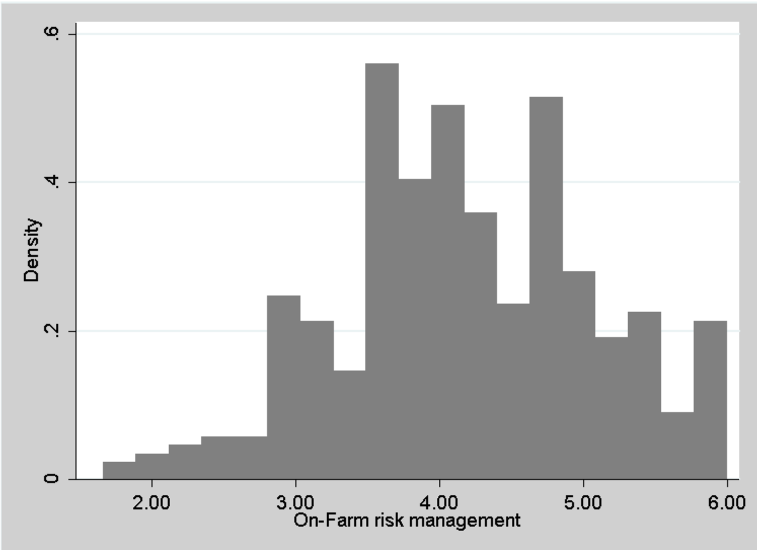

Figure 7: Histogram for on-farm risk management

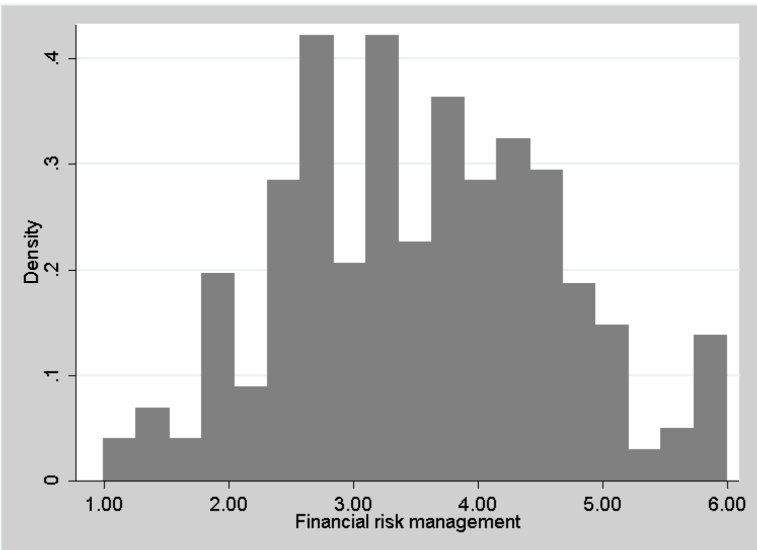

Figure 8: Histogram for financial risk management

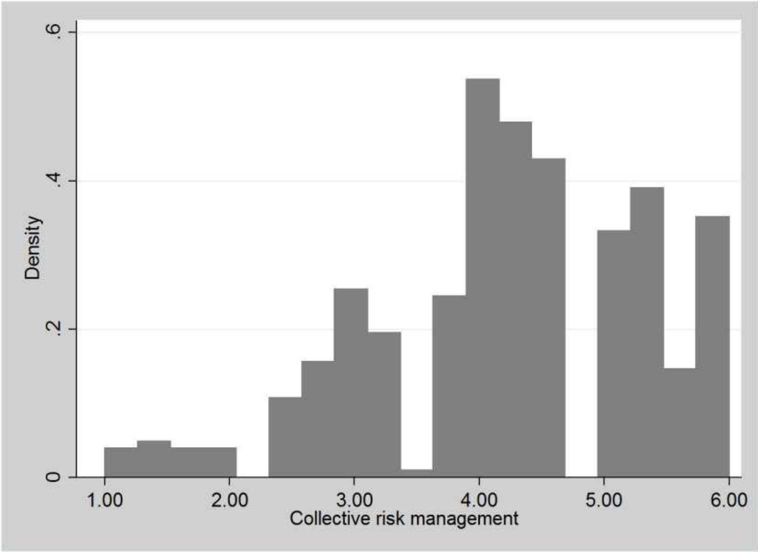

Figure 9: Histogram for collective risk management

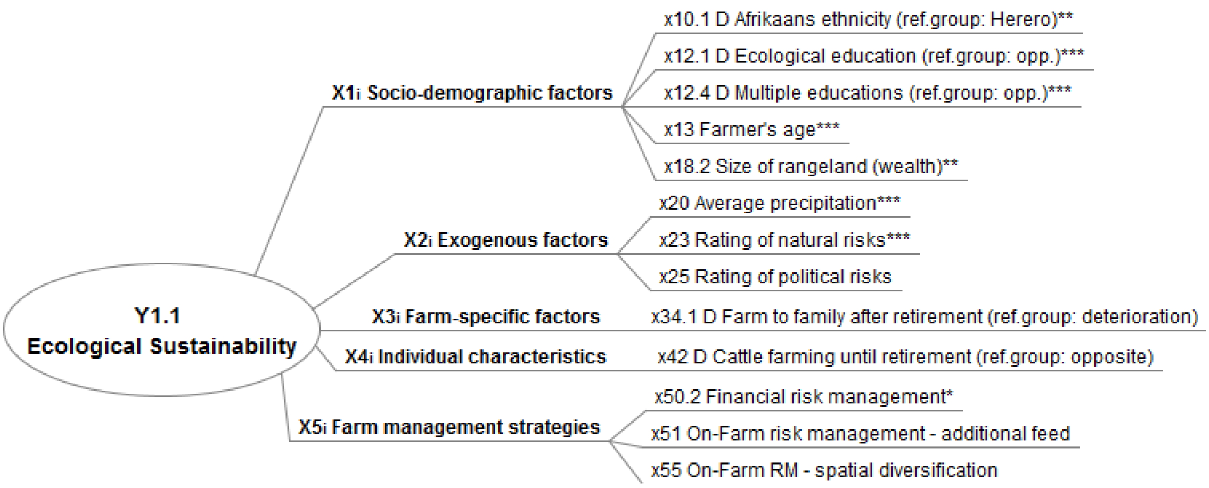

Figure 10: List of variables for the regression analysis of ecological sustainability

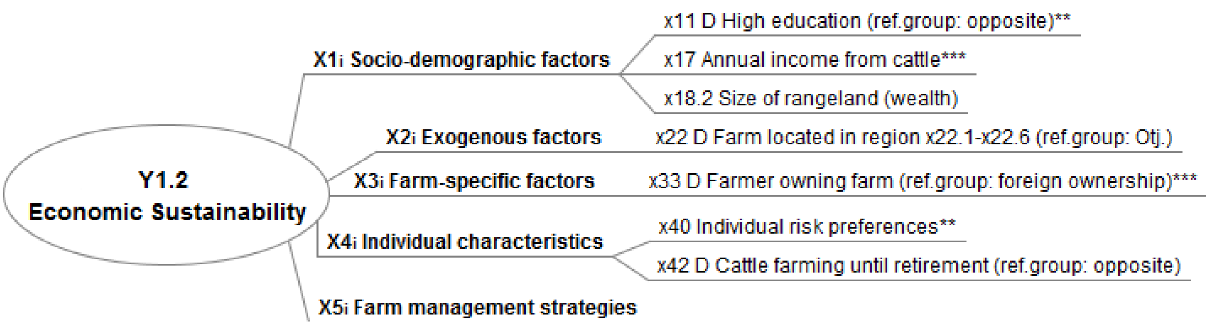

Figure 11: List of variables for the regression analysis of economic sustainability

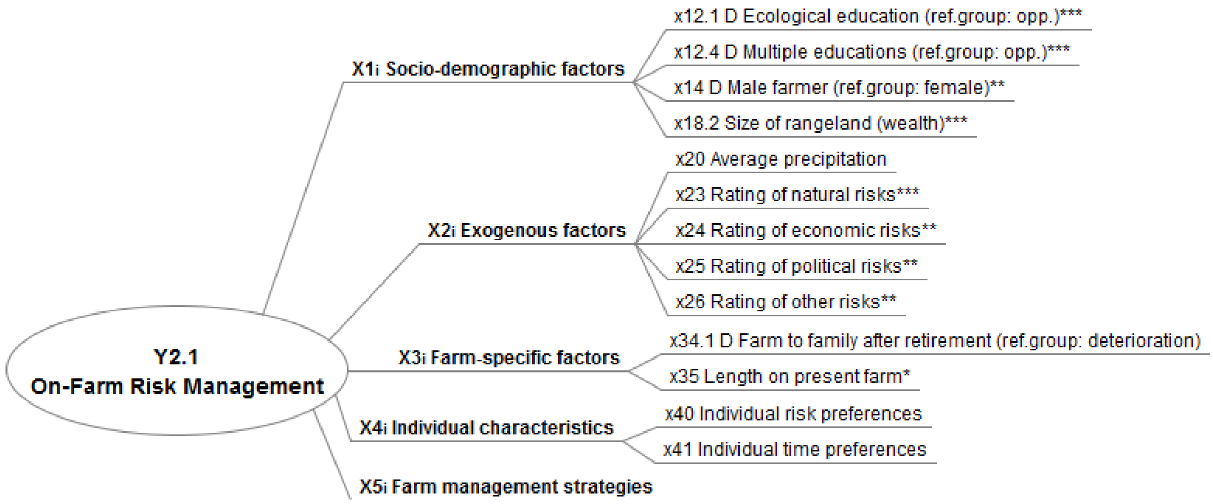

Figure 12: List of variables for the regression analysis of on-farm risk management

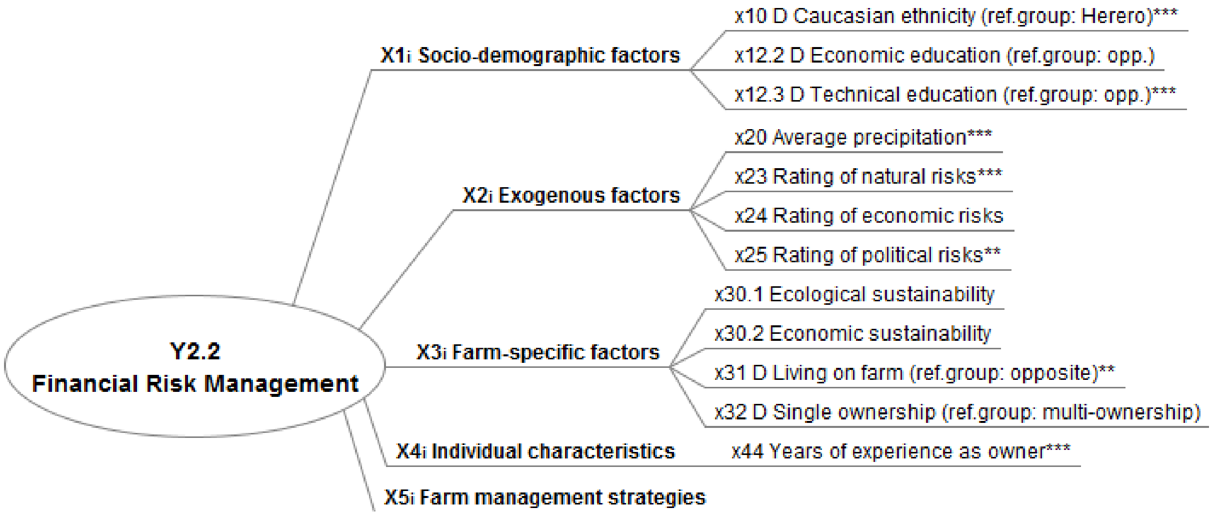

Figure 13: List of variables for the regression analysis of financial risk management

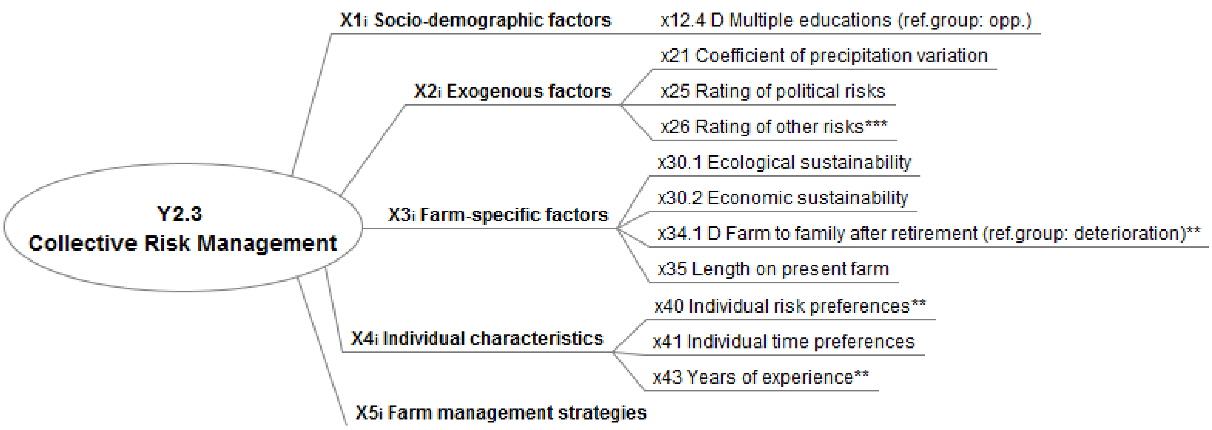

Figure 14: List of variables for the regression analysis of collective risk management

Appendix B: Descriptive statistics, table of summary statistics

Table 1: Summary statistics of all initial independent and dependent variables

Variable	Definition	Mean	Std. dev.	Min	Max
Socio-demographic factors					
Caucasian ethnicity	Of Afrikaans, German, English or Caucasian mixed ethnicity or of Indigenous ethnicity	0.97	0.18	0	1
Afrikaans	Subgroup: Afrikaans, Herero. Of Afrikaans ethnicity	0.94	0.25	0	1
German	Subgroup: German, Herero. Of German ethnicity	0.93	0.25	0	1
High education	Apprenticeship, college or university education	0.57	0.5	0	1
Ecological education	Education in an ecological field of study	0.4	0.49	0	1
Economic education	Education in an economic field of study	0.22	0.41	0	1
Technical education	Education in a technical field of study	0.25	0.43	0	1
Multiple educations	Education in more than one of the above listed fields of study	0.1	0.3	0	1
Age	Farmer's age (reference year: 2008)	55.37	11.9	27	90
Male	Male gender	0.95	0.22	0	1
Emerging farmer	Belonging to the group of emerging farmers	0.14	0.35	0	1
Total income	Total annual income in N$	195,572.2	129,413.1	25,000	400,000
Income from cattle farming	Annual income fraction derived from cattle farming in N$	109,574.2	96,798.21	0	360,000
Cattle quantity (wealth)	Average number of cattle in rainy season of 2007/2008	435.62	306.63	0	1,560.5
Rangeland size (wealth)	Area of land used for cattle farming	7,544.88	4366.88	0	23,300
Exogenous factors					
Average precipitation	Average precipitation in wet seasons (for period 1978-2008)	277.63	86.43	63.35	464.02
Coefficient of precipitation variability	Coefficient of variation in precipitation in wet seasons (for period 1978-2008)	0.28	0.03	0.21	0.39
Unfavourable region	Farm located in either Erongo, Hardap, Karas, Khomas, Kunene, Omaheke or Oshikoto	0.65	0.48	0	1

Erongo	Subgroup: Erongo, Otjozondjupa. Farm located in Erongo	0.14	0.34	0	1
Hardap/Karas	Subgroup: Hardap, Karas, Otjozondjupa. Farm located in Hardap or Karas	0.09	0.29	0	1
Khomas	Subgroup: Khomas, Otjozondjupa. Farm located in Khomas	0.37	0.48	0	1
Kunene	Subgroup: Kunene, Otjozondjupa. Farm located in Kunene	0.22	0.41	0	1
Omaheke	Subgroup: Omaheke, Otjozondjupa. Farm located in Omaheke	0.39	0.49	0	1
Oshikoto	Subgroup: Oshikoto, Otjozondjupa. Farm located in Oshikoto	0.07	0.26	0	1
Environmental risks	Natural risks like no rainfall, bush fires, cattle diseases or predators	4.14	1.11	1.25	6
Economic risks	Economic risks like unfavourable prices or rising living expenses	5.13	0.82	2.67	6
Political risks	Political risks like unfavourable trade agreements, changing labour market conditions or expropriation	4.96	0.89	2.33	6
Other risks	Other risks like cattle theft or machine failure	3.88	1.22	1	6
Farm-specific factors					
Ecological sustainability	Difference between actual bush cover proportion on rangeland and sustainable bush cover, in %	-16.31	17.03	-69	0
Economic sustainability	Difference between actual income and sustainable income threshold, in N$	-149,108.6	140,798.8	-717,500	0
Living on farm	Farmer lives on farm during week, proxy for full-time farming	0.8	0.4	0	1
Single ownership of farm	Farm business structure is a single proprietorship	0.71	0.46	0	1
Farmer's status on farm	Farmer as principal operator on farm is also the farm's owner	0.92	0.27	0	1
Farm future: stays with family	After the present farmer retires the farm will be continued by the family	0.96	0.2	0	1
Farm future: will be sold	After the present farmer retires the farm will be sold	0.83	0.38	0	1
Farm future: gets a new manager	After the present farmer retires a new manager will be hired	0.62	0.49	0	1

Operation time on farm	Farmer's time of operation on the present farm (in years)	20.88	12.95	0	57
Individual characteristics					
Risk preferences	Farmer's willingness to take risks	4.34	1.81	1	7
Time preferences	Farmer's willingness to wait	5.46	2.49	1	9
Lifetime farmer	Continuation of cattle farming until retirement	0.85	0.36	0	1
Farm experience	Experience in farming in years	24.88	13.41	0	65
Owner experience	Experience as owner in years	20.71	13.33	0	57
Farm management strategies					
Risk management on farm	Average importance of on-farm management, such as additional feed, resting rangeland or diversification	4.19	0.89	1.67	6
Financial risk management	Average importance of financial risk management, such as agricultural derivatives or off-farm income	3.55	1.08	1	6
Collective risk management	Average importance of collective risk management, such as cooperative ownership if interest groups	4.26	1.13	1	6
Risk management on farm: Feed	On farm risk management strategy: Purchase of supplementary feed	4.66	1.52	1	6
Risk management on farm: Production system	On farm risk management strategy: Choice of cattle production system	4.42	1.42	1	6
Risk management on farm: Breed	On farm risk management strategy: Choice of breed adapted to high variability in grass production	4.55	1.34	1	6
Risk management on farm: Resting rangeland	On farm risk management strategy: Resting part of rangeland in good rainy seasons as buffer for bad seasons	4.66	1.52	1	6
Risk management on farm: Diversify	On farm risk management strategy: Purchase/lease of extra rangeland in areas with different rainfall patterns	3.25	1.72	1	6
Risk management on farm: scale effects	On farm risk management strategy: Purchase/lease of extra rangeland for scale effects	3.27	1.68	1	6

Appendix C: Descriptive statistics, figures, frequency tables

Table 2: Frequency table for ethnicity

Ethnicity	No.	Col. %	Cum. %
Afrikaans	182	46.1	46.1
German	179	45.3	91.4
Herero	13	3.3	94.7
Ovambo	3	0.8	95.4
Nama/Damara	2	0.5	95.9
English	5	1.3	97.2
Mixed ethnic backgrounds and others	11	2.8	100.0
Total	395	100.0	

Table 3: Frequency table for the level of education

Education level	No.	Col. %	Cum. %
No high school graduation	19	4.8	4.8
High school graduation	93	23.5	28.3
Apprenticeship	58	14.7	43.0
University Diploma	172	43.6	86.6
University Master	42	10.6	97.2
Doctor	11	2.8	100.0
Total	395	100.0	

Table 4: Frequency table for the field of education

Field of education	No.	Col. %	Cum. %
Ecological education	84	30.2	30.2
Economic education	38	13.7	43.9
Technical education	63	22.6	66.5
Education in multiple fields of study	28	10.1	76.6
Education in fields of study other than enlisted	65	23.4	100.0
Total	278	100.0	

Table 5: Frequency table for age

Age	No.	Col. %	Cum. %
25 to 30	4	1.0	1.0
31 to 35	13	3.3	4.3
36 to 40	32	8.1	12.4
41 to 45	31	7.8	20.3
46 to 50	60	15.2	35.4
51 to 55	60	15.2	50.6
56 to 60	67	17.0	67.6
61 to 65	48	12.2	79.7
66 to 70	37	9.4	89.1
71 to 75	26	6.6	95.7
76 to 80	8	2.0	97.7
81 to 85	5	1.3	99.0
86 to 90	4	1.0	100.0
Total	395	100.0	

Table 6: Frequency table for gender

Gender	No.	Col. %	Cum. %
Male	376	94.7	94.7
Female	21	5.3	100.0
Total	397	100.0	

Table 7: Frequency table for the income from cattle farming

Income from farming	No.	Col. %	Cum. %
0%	24	6.3	6.3
1 to 20%	47	12.2	18.5
21 to 40%	50	13.0	31.5
41 to 60%	69	18.0	49.5
61 to 80%	82	21.4	70.8
81 to 100%	112	29.2	100.00
Total	384	100.0	

Table 8: Frequency table for the rangeland size

Rangeland size	No.	Col. %	Cum. %
0 ha	1	0.3	0.3
1 to 2,500 ha	29	7.5	7.8
2,501 to 5,000 ha	97	25.1	32.9
5,001 to 7,500 ha	97	25.1	58.0
7,501 to 10,000 ha	77	20.0	78.0
10,001 to 12,500 ha	37	9.6	87.6
12,501 to 15,000 ha	21	5.4	93.0
15,001 to 17,500 ha	10	2.6	95.6
17,501 to 20,000 ha	13	3.4	99.0
20,001 or more ha	4	1.0	100.0
Total	386	100.0	

Table 9: Frequency table for the average annual precipitation

Average precipitation	No.	Col. %	Cum. %
0 to 100 mm	7	2.4	2.4
>100 to 200 mm	54	18.5	20.9
>200 to 300 mm	109	37.3	58.2
>300 to 400 mm	95	32.5	90.8
>400 mm	27	9.3	100.0
Total	292	100.0	

Table 10: Frequency table for the variation in precipitation

Variation in precipitation	No.	Col. %	Cum. %
0 to 10%	0	0.0	0.0
>10 to 20%	0	0.0	0.0
>20 to 30%	205	71.2	71.2
>30 to 40%	83	28.8	100.0
>40%	0	0.0	100.0
Total	288	100.0	

Table 11: Frequency table for the region

Location of the farm	No.	Col. %	Cum. %
Erongo	22	5.6	5.6
Hardap	11	2.8	8.4
Karas	3	0.8	9.1
Khomas	81	20.5	29.6
Kunene	39	9.9	39.5
Omaheke	88	22.3	61.8
Oshikoto	11	2.8	64.6
Otjozondjupa	140	35.4	100.0
Total	395	100.0	

Table 12: Frequency table for the rating of natural risks

Natural risks	No.	Col. %	Cum. %
1 to <1.5 (no risk)	1	0.3	0.3
1.5 to <2.5	27	6.9	7.1
2.5 to <3.5	75	19.1	26.3
3.5 to <4.5	118	30.1	56.4
4.5 to <5.5	118	30.1	86.5
5.5 to 6 (very high risk)	53	13.5	100.0
Total	392	100.0	

Table 13: Frequency table for the rating of economic risks

Economic risks	No.	Col. %	Cum. %
1 to <1.5 (no risk)	0	0.0	0.0
1.5 to <2.5	0	0.0	0.0
2.5 to <3.5	14	3.6	3.6
3.5 to <4.5	77	19.9	23.5
4.5 to <5.5	143	36.9	60.3
5.5 to 6 (very high risk)	154	39.7	100.0
Total	388	100.0	

Table 14: Frequency table for the rating of political risks

Political risks	No.	Col. %	Cum. %
1 to <1.5 (no risk)	0	0.0	0.0
1.5 to <2.5	3	0.8	0.8
2.5 to <3.5	21	5.6	6.4
3.5 to <4.5	85	22.7	29.1
4.5 to <5.5	140	37.4	66.6
5.5 to 6 (very high risk)	125	33.4	100.0
Total	374	100.0	

Table 15: Frequency table for the rating of further risks

Other risks	No.	Col. %	Cum. %
1 to <1.5 (no risk)	4	1.0	1.0
1.5 to <2.5	37	9.4	10.4
2.5 to <3.5	88	22.3	32.7
3.5 to <4.5	116	29.4	62.2
4.5 to <5.5	91	23.1	85.3
5.5 to 6 (very high risk)	58	14.7	100.0
Total	394	100.0	

Table 16: Frequency table for ecological sustainability on farm

Ecological sustainability	No.	Col. %	Cum. %
Up to -70%*	0	0.0	0.0
-70% to -60%	8	2.5	2.5
-60% to -50%	16	4.9	7.4
-50% to -40%	19	5.9	13.2
-40% to -30%	52	16.0	29.2
-30% to -20%	44	13.5	42.8
-20% to -10%	53	16.3	59.1
-10% to 0%	133	40.9	100.0
Total	325	100.0	

*At least 70% surplus of actual bush cover over the indicated threshold level for optimal bush cover.

Table 17: Frequency table for economic sustainability on farm

Economic sustainability	No.	Col. %	Cum. %
Up to N$ -700,000*	2	0.7	0.7
Over N$ -700,000 to N$ -600,000	1	0.3	1.0
Over N$ -600,000 to N$ -500,000	5	1.7	2.7
Over N$ -500,000 to N$ -400,000	14	4.6	7.3
Over N$ -400,000 to N$ -300,000	22	7.3	14.6
Over N$ -300,000 to N$ -200,000	40	13.3	27.9
Over N$ -200,000 to N$ -100,000	91	30.2	58.1
Over N$ -100,000 to N$ 0	126	41.9	100.0
Total	301	100.0	

*At least N$ 700,000 of annual income missing to reach the indicated income threshold level.

Table 18: Frequency table for living on farm

Living on farm	No.	Col. %	Cum. %
Living on farm	317	80.1	80.1
Not living on farm	79	20.0	100.0
Total	396	100.0	

Table 19: Frequency table for the ownership structure of the farm

Proprietorship	No.	Col. %	Cum. %
Single ownership	269	70.6	70.6
Partnership, trust or foundation	20	5.3	75.9
Cooperative	9	2.4	78.2
Corporation	83	21.8	100.0
Total	381	100.0	

Table 20: Frequency table for the ownership of the farm

Farmer's status	No.	Col. %	Cum. %
Farmer is owner	360	91.4	91.4
Farmer is a hired manager	11	2.8	94.2
Farmer is a tenant/leaser	14	3.6	97.7
Other status	9	2.3	100.0
Total	394	100.0	

Table 21: Frequency table for the farm future after retirement

Fates of farm	No.	Col. %	Cum. %
Continued by family	249	67.7	67.7
Sold	55	15.0	82.6
New manager	18	4.9	87.5
Dissolved or deterioration	11	3.0	90.5
No plans or other plans for future	35	9.5	100.0
Total	368	100.0	

Table 22: Frequency table for the operation time on farm

Operation time on farm	No.	Col. %	Cum. %
Zero up to 10 years	94	24.4	24.4
From over 10 to 20 years	112	29.1	53.5
From over 20 to 30 years	87	22.6	76.1
From over 30 to 40 years	62	16.1	92.2
From over 40 to 50 years	24	6.2	98.4
From over 50 to 60 years	6	1.6	100.0
Total	385	100.0	

Table 23: Frequency table for farming experience

Years of experience	No.	Col. %	Cum. %
10 years or less	65	16.6	16.6
11 to 20 years	109	27.9	44.5
21 to 30 years	96	24.6	69.1
31 to 40 years	73	18.7	87.7
41 to 50 years	35	9.0	96.7
51 to 60 years	11	2.8	99.5
61 years or more	2	0.5	100.0
Total	391	100.0	

Table 24: Frequency table for farming experience as an owner

Experience as owner	No.	Col. %	Cum. %
10 years or less	106	27.0	27.0
11 to 20 years	101	25.7	52.7
21 to 30 years	97	24.7	77.4
31 to 40 years	65	16.5	93.9
41 to 50 years	19	4.8	98.7
51 to 60 years	5	1.3	100.0
Total	393	100.0	

Table 25: Frequency table for risk preferences

Risk preferences	No.	Col. %	Cum. %
1 (Avoiding risks)	26	7.3	7.3
2	50	14.1	21.5
3	37	10.5	31.9
4	60	17.0	48.9
5	66	18.6	67.5
6	75	21.2	88.7
7 (Willing to take risks)	40	11.3	100.0
Total	354	100.0	

Table 26: Frequency table for time preferences

Time preferences	No.	Col. %	Cum. %
1 (Not at all willing to wait)	45	11.7	11.7
2	19	4.9	16.6
3	29	7.5	24.1
4	25	6.5	30.6
5	61	15.8	46.4
6	50	13.0	59.3
7	72	18.7	78.0
8	36	9.3	87.3
9 (Very willing to wait)	49	12.7	100.0
Total	386	100.0	

Table 27: Frequency table for planned operation time

Planned operation time on farm	No.	Col. %	Cum. %
10 years or less	122	31.9	31.9
11 to 20 years	113	29.6	61.5
21 to 30 years	34	8.9	70.4
31 to 40 years	15	3.9	74.4
More than 40 years	6	1.6	75.9
Until death	76	19.9	95.8
Until children take over	3	0.8	96.6
Do not know	13	3.4	100.0
Total	385	100.0	

Table 28: Frequency table for on-farm risk management

On-Farm risk management	No.	Col. %	Cum. %
1 (not at all important)	0	0.0	0.0
2	5	1.3	1.3
3	36	9.2	10.5
4	140	35.7	46.2
5	147	37.5	83.7
6 (very important)	64	16.3	100.0
Total	392	100.0	

Table 29: Frequency table for financial risk management

Financial risk management	No.	Col. %	Cum. %
1 (not at all important)	3	0.8	0.8
2	32	8.3	9.0
3	102	26.3	35.3
4	132	34.0	69.3
5	91	23.5	92.8
6 (very important)	28	7.2	100.0
Total	388	100.0	

Table 30: Frequency table for collective risk management

Collective risk management	No.	Col. %	Cum. %
1 (not at all important)	4	1.0	1.0
2	13	3.3	4.4
3	53	13.6	18.0
4	101	26.0	44.0
5	127	32.7	76.6
6 (very important)	91	23.4	100.0
Total	389	100.0	

Table 31: Frequency table for on-farm risk management: additional feed

Management strategy: Additional feed	No.	Col. %	Cum. %
1 (not at all important)	24	6.1	6.1
2	24	6.1	12.2
3	33	8.4	20.5
4	64	16.2	36.7
5	86	21.8	58.5
6 (very important)	164	41.5	100.0
Total	395	100.0	

Table 32: Frequency table for on-farm risk management: Diversification

Management strategy: Spatial diversification	No.	Col. %	Cum. %
1 (not at all important)	89	23.5	23.5
2	60	15.8	39.3
3	50	13.2	52.5
4	69	18.2	70.7
5	68	17.9	88.7
6 (very important)	43	11.4	100.0
Total	379	100.0	

Appendix D: Results, regression analysis

Table 33: Regression analysis for ecological sustainability.
OLS regression, with standard errors in brackets. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Dependent variable:	**Ecological sustainability**
High education	8.61566** (3.35371)
Ecological education	-9.944299*** (3.250195)
Multiple educations	11.87873*** (4.43527)
Age (in years)	0.4806203*** (0.1441651)
Rangeland size (in ha)	-0.0006412** (0.0002815)
Average annual rain (in mm)	-0.0759349*** (0.0160592)
Natural risks	-4.826824*** (1. 455285)
Political risks	-0.6805058 (1.87886)
Farm to family after retirement	3.349574 (7.242033)
Lifetime farmer	-5.177437 (3.70943)
On-Farm risk management: Additional feed	1.230698 (1.130282)
On-Farm risk management: Spatial diversification	-0.8528996 (0.8654117)
Financial risk management	3.938432** (1.693139)
Constant	-13.8266 (15.8419)
R^2 Adjusted R^2	0.4225 0.3409
F-statistic Model significance	5.18 0.0000
Observations	106

Table 34: Impact of risk management strategies on ecological sustainability.
OLS regression, with standard errors in brackets. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Dependent variable:	**Ecological sustainability**
High education	9.238738*** (3.401213)
Ecological education	-9.492879*** (3.324675)
Multiple educations	12.03076** (4.622929)
Age	0.4842903*** (0.1446231)
Rangeland size (in ha)	-0.0006084** (0.0002872)
Average annual rain (in mm)	-0.077922*** (0.016303)
Natural risks	-4.761143*** (1.465082)
Political risks	0.0151027 (1.968734)
Farm to family after retirement	5.163568 (7.431267)
Farming until retirement	-5.267515 (3.720637)
On-Farm risk management	-1.102322 (2.736971)
On-Farm risk management: Additional feed	1.434667 (1.198132)
On-Farm risk management: Spatial diversification	-0.534146 (1.233519)
Financial management strategies	4.376446** (1.746512)
Collective management strategies	-1.732305 (1.602321)
Constant	-11.56363 (16.30889)
R^2 Adjusted R^2	0.4322 0.3375
F-statistic Model significance	4.57 0.0000
Observations	106

Table 35: Regression analysis for economic sustainability, with and without constant.
OLS regression, with standard errors in brackets. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Dependent variable:	**Economic sustainability**	
High education	-34,667.83** (16,597.9)	-34,481.13** (16,031.57)
Income from farming (in N$)	0.3296928*** (0.0921135)	0.3304487*** (0.0903655)
Rangeland size (in ha)	-2.123355 (2.002549)	-2.110181 (1.976737)
Unfavourable region	-4,716.642 (16,839.87)	-4,475.61 (15,921.54)
Ownership	-89,029.53*** (31,265.02)	-88,172.51*** (24,651.92)
Risk preferences	-10,758.41** (4,386.593)	-10,687.8*** (4,084.225)
Farming until retirement	16,156.74 (21,453.47)	-15,706.43 (18,904.73)
Constant	2,012.221 (44,998.64)	--
R^2 Adjusted R^2	0.1252 0.1002	0.6092 0.5981
F-statistic Model significance	5.01 0.0000	54.78 0.0000
Observations	253	253

Table 36: Impact of risk management strategies on economic sustainability.
OLS regression, with standard errors in brackets. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Dependent variable:	**Economic sustainability**
High education	-37,233.57** (17739.38)
Income from farming (in N$)	0.3619908*** (0.0990031)
Rangeland size (in ha)	-1.434931 (2.135373)
Unfavourable region	-8,864.357 (17836.98)
Ownership	-92,854.35*** (32,783.04)
Risk preferences	-11,762.44** (4,734.826)
Farming until retirement	85.12529 (22,744.57)
On-Farm management strategies	-2,372.978 (11,406.08)
Financial management strategies	-7,570.997 (9743.603)
Collective management strategies	2,782.714 (8,794.714)
Constant	11,790.59 (69,302.88)
R^2 Adjusted R^2	0.1381 0.1014
F-statistic Model significance	3.77 0.0001
Observations	246

Table 37: Regression analysis for on-farm risk management.
OLS regression, with standard errors in brackets. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Dependent variable:	**On-Farm risk management**
Ecological education	0.4711719*** (0.1703102)
Multiple educations	-0.7657581*** (0.2391326)
Male	-1.187353** (0.5819788)
Rangeland size	0.0000465*** (0.0000154)
Average precipitation	0.0007359 (0.0008563)
Natural risks	0.2897818*** (0.0811201)
Economic risks	0.1984936** (0.0990606)
Political risks	0.2229703** (0.1057742)
Other risks	-0.1905016** (0.0852391)
Farm to family after retirement	-0.0285938 (0.3422321)
Operation time	-0.0114071* (0.0066995)
Risk preferences	-0.0122646 (0.0421157)
Time preferences	0.0291239 (0.0319692)
Constant	2.253309** (0.8846238)
R^2 Adjusted R^2	0.3762 0.2982
F-statistic Model significance	4.82 0.0000
Observations	118

Table 38: Impact of sustainability on on-farm risk management.
OLS regression, with standard errors in brackets. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Dependent variable:	**On-Farm risk management**
Ecological education	0.54888897*** (0.1868017)
Multiple educations	-0.8946563*** (0.25233)
Male	-1.312844** (0.5553968)
Rangeland size	0.0000315* (0.0000158)
Average precipitation	0.0012018 (0.0010663)
Natural risks	0.2351959*** (0.0869685)
Economic risks	0.128195 (0.1061865)
Political risks	0.1439297 (0.1185579)
Other risks	-0.1649934 (0.0993274)
Farm to family after retirement	0.2145283 (0.3436107)
Operation time	-0.0164276** (0.0076853)
Risk preferences	0.0067731 (0.0439206)
Time preferences	0.0491419 (0.0360622)
Ecological sustainability	0.0015591 (0.0053836)
Economic sustainability	-0.0000002 (0.0000006)
Constant	2.903821*** (0.910145)
R^2 Adjusted R^2	0.4115 0.2906
F-statistic Model significance	3.40 0.0002
Observations	89

Table 39: Regression analysis for financial risk management, including sustainability.
OLS regression, with standard errors in brackets. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Dependent variable:	**Financial risk management**
Caucasian ethnicity	-1.148198*** (0.4166633)
Economic education	-0.0916933 (0.1782949)
Technical education	0.4671501*** (0.1728998)
Average precipitation	0.0024945*** (0.000892)
Natural risks	0.2915831*** (0.067184)
Economic risks	0.1484118 (0.0944311)
Political risks	0.2235924** (0.0988014)
Living on farm	-0.4099131** (0.1748385)
Single ownership	-0.0820491 (0.1619151)
Experience as owner	0.0183937*** (0.0064164)
Ecological sustainability	0.0070403 (0.0045537)
Economic sustainability	-4.21e-07 (5.03e-07)
Constant	0.970188 (0.7614662)
R^2 Adjusted R^2	0.4607 0.4093
F-statistic Model significance	8.97 0.0000
Observations	139

Table 40: Regression analysis for collective risk management, including sustainability.
OLS regression, with standard errors in brackets. Significance levels: *** p<0.01, ** p<0.05, * p<0.1.

Dependent variable:	**Collective risk management**
Multiple educations	0.2916656 (0.2475076)
Coefficient of variation in precipitation	2.957418 (2.776322)
Political risks	0.133539 (0.1308933)
Other risks	0.334032*** (0.0931452)
Farm to family after retirement	0.9568304** (0.4003214)
Operation time on farm	-0.0221818 (0.0136397)
Risk preferences	-0.09943** (0.0492292)
Time preferences	0.0401136 (0.0414121)
Years of experience	0.0309389** (0.0132405)
Ecological sustainability	0.0005644 (0.0053671)
Economic sustainability	1.05e-07 (6.98e-07)
Constant	0.4503958 (1.174557)
R^2 Adjusted R^2	0.3534 0.2586
F-statistic Model significance	3.73 0.0003
Observations	87

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