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Risk preferences under heterogeneous environmental risk

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Abstract

We study risk preferences and their determinants for commercial cattle farmers in Namibia who are subject to high and heterogeneous precipitation risk, using data from questionnaire and field experiments, simulated data for on-farm precipitation risk and data on famers' previous place of residence. We find that the relationship between risk preferences and precipitation risk is contingent on early-life experience with this risk. We also find that adult farmers self-select themselves onto farms according to their risk preferences. Results are not confounded by background risks or liquidity constraint.

Keywords: risk preferences, environmental risk, experimental elicitation, endogenous preferences, self-selection, field experiment

JEL-Classification: D81, Q12, Q57

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1. Introduction

Behavior towards risk, as the interplay between risk preferences and the opportunity set, plays an important role in economic life. Everybody experiences risks in one's every-day economic life. But few people experience the same type of risk that determines their income throughout their entire life. Rangeland farmers in semi-arid regions are among them, with their livelihood essentially depending on environmental risks. These farmers are therefore particularly well suited to study the determinants that drive risk behavior, especially risk preferences.

Previous studies on the interaction between risk preferences and environmental risk assumed risk preferences to be stable and then examined how a change in risk constraints induces a behavioral change (e.g. Rosenzweig and Binswanger, 1993). However, recent studies demonstrate that risk preferences endogenously change with external cues such as market arrangements (Palacios-Huerta and Santos, 2004), civil war shocks (Voors et al., 2011) and possibly macroeconomic shocks (Malmendier and Nagel, 2011). In this paper, we empirically study risk preferences and their determinants, with a specific focus on whether risk preferences change with early-life experience with environmental risk.

Our case study is commercial cattle farming in semi-arid rangelands of Namibia. Farmers in these areas experience a variety of socio-economic and environmental risks, predominant among which is precipitation risk. Annual precipitation in Namibia is low with an average of approximately 270 mm, and spatially and temporally highly variable (Sweet, 1998; Ward et al., 2004; Wiegand et al., 2005; Chapman, 2010, see also Figure 1). In addition to precipitation risk, farmers face prices risk for inputs and outputs, the latter of which comprise of cattle sold to the slaughterhouse or at local auctions. These prices may be very volatile; for example, prices for auction sales may increase or decrease by more than 50% from one year to the next (Olbrich et al., 2011c). In commercial cattle farming, land property rights are assigned to individual farmers.[1] The market for farmland is well developed which allows the purchase of farms anywhere within the commercial farming region. Roughly half of the farmer population operates on a farm that they purchased , whereas the other half stays on the farm where they grew up and which they took over from their parents.

We experimentally elicit risk preferences both in questionnaire experiments with hypothetical payouts and in-field experiments with real payouts in August 2008. The farms operated by the participants in the experiments are distributed over the whole region in Namibia where

[1] In this respect, commercial cattle farming differs from communal farming, the other main farming system performed in northern and eastern Namibia, where rangelands are used as a common property resource mainly for subsistence farming.

commercial cattle farming is common (Figure 1) (Mendelsohn, 2006: 43). We complement our survey data with actual and simulated on-farm precipitation data and by farm records of the Deed's Office of Namibia which detail farm ownership since 1920. We investigate the impact of precipitation risk[2] and experience with this risk during childhood and adolescence on the coefficient of relative risk aversion by maximum likelihood estimation, controlling for socio-demographic variables, liquidity constraint and price background risk.

We find that risk aversion and environmental risk are negatively related if we do not account for prior risk experience. This observation is consistent with self-selection where *more* risk averse farmers occupy *less* risky farms. However, once we take into account prior risk experience during childhood and adolescence we find that risk preferences are endogenous with respect to environmental risk: among those farmers who grew up on the farm they currently operate, the individual is *more* risk averse the more years it has spent on this farm prior to age 18 years. Eventually, past risk experience becomes the dominant feature of the relationship between risk preferences and environmental risk: farmers who grew up on their farm for at least 10 years during childhood or adolescence are the *more* risk averse the higher the precipitation risk is on their farm, i.e. the *more* risky their farm is. We thus conclude that risk preferences are endogenous with respect to environmental risk.

We can exclude two alternative explanations for our results. Precipitation risk may act as a background risk to choices in our risk experiments, but we can exclude its possibly confounding influence on the grounds of previous literature findings pertaining to the sign of its effect on risk aversion. Liquidity constraint has no significant influence on risk aversion, and all price-background risks are homogenous across farmers and therefore cannot explain individual heterogeneity in behavior towards risk.

The paper is organized as follows. Section 2 explains the conceptual background. Section 3 describes the methods used to collect and analyze our data. Results are presented in Section 4. Section 5 discusses and concludes.

[2] One might argue that the relevant risk is profits from cattle farming and not precipitation. However, from qualitative interviews with farmers we infer that they are preoccupied with precipitation of which they keep very detailed records. Conversely, data on profits are seldom recorded. We thus assume that precipitation is indeed the relevant risk and that the profit risk (in the mindset of farmers) is linearly related to precipitation risk.

2. Conceptual background and hypotheses

The relationship between an individual's risk preferences and risk can be driven by formation of risk preferences through given risk conditions ("endogeneity of risk preferences") and by choice of risk conditions according to given risk preferences ("self-selection"). In this section, we explain these two mechanisms and derive hypotheses concerning endogeneity of preferences and self-selection that pertain to commercial cattle farming in Namibia.

2.1 Endogeneity of risk preferences

One possible mechanism driving the relationship between risk preferences and risk is that preferences are formed by given risk conditions that individuals experience. Endogeneity of risk preferences has been studied for a variety of contexts. They are relatively stable over time (Harrison et al., 2005b; Andersen et al., 2008b; Sahm, 2008), with respect to changes in income and wealth (Brunnermeier and Nagel, 2008; Sahm, 2008) and under major shocks like job displacement (Sahm, 2008). However, they change with age (Dohmen et al., 2005; Sahm, 2008; Harrison et al., 2010) and are endogenous with respect to external cues. Palacios-Huerta and Santos (2004), assuming a general equilibrium model in which preferences are endogenous with respect to market arrangements, observe that individuals are less risk-averse when markets are incomplete and provide less institutional risk mitigation which consequently leave those individuals more vulnerable to risk. Voors et al. (2011) study how risk preferences are affected by civil war shocks. They find, that those individuals who experienced higher violence, in the sense that their community has suffered a higher number of casualties, were more risk seeking. Finally, Malmendier and Nagel (2011) find that individuals who have experienced worse stock and bond market conditions, in the form of low returns, take less financial risks. They attribute this relationship to formation of more pessimistic beliefs about future returns, but cannot discard the possibility of endogeneity of risk preferences. As of yet, no economic study considered environmental risk as an external cue that may form risk preferences. Moreover, to our knowledge no economic study has yet examined childhood or adolescence as a period of risk preference formation, even though this period is critical for the formation of a variety of preferences (e.g. Cunha & Heckman 2007, Borghans et al. 2008, Cunha et al. 2010).

Insights on requirements and processes for formation of risk preferences are provided by the psychological literature. Firstly, important cognitive requirements for risk preferences such as logical reasoning are in place at the end of childhood (e.g. Boyer, 2006; Reyna and Farley, 2006), meaning that older children and adolescents do indeed have risk preferences that allow a rational evaluation of risky alternatives. Secondly, these preferences may change during childhood and adolescence through a variety of processes. One of these processes is a systematic preference shift with age in response to certain external cues an individual experiences (Bowles, 1998; Loewenstein and Angner, 2003) – a process called *maturation* (Loewenstein and Angner, 2003). In maturation, preferences may shift more strongly the longer the cue is experienced, but eventually ‘different types of preferences tend to become “frozen” at different periods in one’s life … [and thereby people] become increasingly inoculated against external influences’ (Loewenstein and Angner, 2003: 363) (similarly Holbrook and Schindler, 2003). For example, people prefer throughout their life the movie stars photographs of their teens (Holbrook and Schindler, 1994) and the music of their mid-twenties (Holbrook and Schindler, 1989), and young adulthood is an important period for the formation of political parties preferences (Gerber and Green, 1998).

Turning to commercial cattle farming in Namibia we first note that this farming is driven by precipitation risk. Along the lines of *maturation*, precipitation risk may constitute a strong external cue that acts on farmers’ risk preferences throughout childhood and adolescence. Thus, we hypothesize that farmers’ risk preferences are endogenous with respect to the precipitation risk experienced during childhood and adolescence and that precipitation risk forms preferences more strongly the longer farmers have experienced this risk.

2.2 Self-selection on the land market

Another possible mechanism driving the relationship between risk preferences and risk is that individuals self-select themselves into risk conditions according to their given risk preferences, with more risk averse individuals choosing less risky conditions. Evidence conform with self-selection has been observed, for example, in regards to occupational choice (Dohmen et al., 2005; Guiso and Paiella, 2005; Bellemare and Shearer, 2010; Jaeger et al., 2010) , investment choice (Dohmen et al., 2005; Guiso and Paiella, 2005) and health behavior (Dohmen et al., 2005).

For commercial cattle farmers in Namibia the land market is the main mechanism that may lead to a self-selection of farmers onto farms differing in precipitation risk according to their risk preferences. To be precise about how self-selection on such a land market works, consider the following model of rangeland farming and the market for farms. The grazing capacity (i.e. the state of the grass vegetation) of the rangeland is described by a stock variable x_t that follows a geometric Brownian motion with zero mean growth rate (i.e. we consider a steady state) and a standard deviation σ of the growth rate that is determined by uncertainty of rainfall. Using x_0 to denote the state of vegetation at time $t=0$, the state x_t at time t follows a log-normal distribution with mean x_0 and variance $x_0^2\left(\exp(\sigma^2 t)-1\right)$ (Dixit and Pindyck, 1994). Annual rents derived from rangeland farming are proportional to the grazing capacity of the rangeland in the year under consideration. To keep notation simple, we normalize annual income from rangeland farming such that it equals x_t. The farm, in this simple model, is characterized by the expected annual state of the vegetation x_0 and by the standard deviation σ that is determined by rainfall uncertainty at the farm's location. We simply call this farm (x_0,σ). We specify farmer's preferences by the instantaneous utility function $U(x)=\frac{x^{1-r}}{1-r}$ which exhibits constant relative risk aversion with a coefficient of (constant) relative risk aversion r. Further, we use δ to denote the farmer's time preference rate, and assume $\frac{1}{2}r(1-r)\sigma^2+\delta>0$ and $\frac{1}{2}\sigma^2<\delta$ to ensure the existence of an interior solution to the farmer's optimization problem. The condition $\frac{1}{2}\sigma^2<\delta$ states that uncertainty should not grow faster than the discount rate. The condition $\frac{1}{2}r(1-r)\sigma^2+\delta>0$ is always fulfilled for farmers with a coefficient of risk aversion $r<1$. For more risk-averse farmers, $r>1$, a farm that is very risky compared to the farmer's discount rate would be of no use (the present value of utility would be $-\infty$). The condition $\frac{1}{2}r(1-r)\sigma^2+\delta>0$ thus means that we consider only farms for which a risk-averse farmer would offer a positive bid. The expected present value of utility from rangeland farming is given by

$$E\left[\int_0^\infty \frac{x_t^{1-r}}{1-r}\exp(-\delta t)dt\right]=\int_0^\infty \frac{x_0^{1-r}}{1-r}\exp(-\frac{1}{2}r(1-r)\sigma^2 t)\exp(-\delta t)dt=\frac{x_0^{1-r}}{1-r}\frac{1}{\frac{1}{2}r(1-r)\sigma^2+\delta}\ . \quad (1)$$

We now consider the land market where farmers bid for farms. The bidders differ with regard to their risk and time preferences and with regard to their reservation utility levels. We use y_0 to denote the certain and constant income stream that would give rise to the reservation utility level of the farmer under consideration. The maximal constant fraction ϕ of annual income that this farmer is willing to bid for a farm (x_0,σ) is (see Appendix A.1)

$$\phi=1-\frac{y_0}{x_0}\left(1+\frac{r(1-r)\sigma^2}{2\delta}\right)^{\frac{1}{1-r}}. \quad (2)$$

The allocation on this land market is characterized by the following result:

Proposition: *If two farmers with identical discount rates bid the same constant fraction* ϕ *of annual income for a farm* (x_0, σ)*, then the more risk-averse farmer outbids the less risk-averse farmer for all less risky farms* $(x_0, \underline{\sigma})$ *with* $\underline{\sigma} < \sigma$ *and the less risk-averse farmer outbids the more risk-averse farmer for all riskier farms* $(x_0, \bar{\sigma})$ *with* $\bar{\sigma} > \sigma$.

Proof: see Appendix A.1.

Based on the proposition we hypothesize that farmers self-select themselves onto farms according to their given risk preferences in such a way that more risk-averse farmers operate on farms with less risky precipitation conditions.

3. Data and methods

3.1 Data sources

Description of the survey

In August 2008, we elicited risk preferences as well as personal, farm business and environmental characteristics of commercial cattle farmers in Namibia in a quantitative survey, consisting of a mail-in questionnaire and in-field experiments. A detailed description of the survey, its conduction and an analysis of representativeness of the survey population can be found in Olbrich et al. (2009).

We sent out questionnaires to all 1,121 cattle farming members of the Namibia Agricultural Union (NAU), the main interest group of commercial farmers in Namibia, and to all 795 farmers that deliver cattle to MeatCo, by far the largest slaughterhouse in Namibia. We mailed out a first batch of questionnaires in the period 19th – 21st of August 2008, and a second batch as a follow up on the 15th of September 2008.

In addition, we randomly selected 39 NAU members for participation in in-field risk experiments. We visited the majority of these participants (79.4%) on their respective farms, and the remaining ones at pubic locations in major cities. With one exception,[3] each session of experiments started with the participant filling in the questionnaire and was followed by the experiments. Duration of sessions varied between one and two-and-a-half hours.

[3] Upon arrival at the meeting the farmer remarked that his time would not permit both filling-in of the questionnaire and conducting experiments. We thus chose to elicit only selected data in the questionnaire and directly proceeded to the experiments. After the experiments, we asked the farmer to mail or fax us a completed questionnaire, but unfortunately the farmer never sent a questionnaire.

Altogether, we reached 1,916 of an estimated total number of 2,500 commercial cattle farmers (76.6%).[4] 399 questionnaires were returned, equaling a return rate of 20.8%. In the returned questionnaires, response rate for non-sensitive questions exceeded 95% for most questions, and response rate was greater than 90% for sensitive questions such as income. An optional question for identification of the farm was answered by 75.1% of survey participants. This question enables us to pinpoint the location of the farm and link survey data to data from external sources such as precipitation data from the REMO climate model and the farm records of the Deed's Office of Namibia (see below).

In addition to the quantitative survey, we conducted 62 qualitative interviews with farmers and decision makers in the agricultural, financial and political sector in which we discussed vary aspects of commercial cattle farming. Interviews took place throughout four research visits in March/April 2007, October 2007, July/August 2008 and February/March 2010.

Elicitation of risk preferences

We elicited risk preferences in the sense of von-Neumann-Morgenstern expected utility theory (von Neumann and Morgenstern, 1944) by an adapted multiple price list format (Binswanger, 1980; Holt and Laury, 2002; Andersen et al., 2006; Harrison et al., 2010), both through experiments with hypothetical payouts within the questionnaire ("questionnaire experiments") and through in-field experiments ("field experiments") with payouts of real money . In the questionnaire experiments we offered farmers six scenarios, where we framed the lottery in the context of selling cattle at an auction (Table 1a). The auction had two possible outcomes, N$90,000[5] and N$130,000, each occurring with equal probability of 1/2. The expected value of the auction (N$110,000) corresponds to about 1/3 of the annual net income of the average farmer. Instead of taking part in the uncertain auction, farmers could chose to sell to a trader for a certain amount which started at N$100,000 in the first scenario and increased in steps of N$2,500 to N$112,500 in the sixth and last scenario.

In the field experiments the lottery was context-free with two possible outcomes, N$500 and N$2,500, each occurring with equal probability of 1/2. The expected value of N$1,500 corresponds to the value of a calf. To achieve a higher resolution of risk aversion measures, 16 scenarios were presented. The certain amount started at N$550 in the first scenario and increased to N$1,900 in the last scenario (Table 1b). After the subject had made their choices

[4] No census data is available that gives the exact number of cattle farmers. The estimate derives from experts of the Namibia Agricultural Union and the Meat Board of Namibia.

[5] On the 1st of August 2008, N$1,000 equalled €88.14 or US$137.50.

one of the chosen scenarios was randomly picked (by throwing a dice) and paid out, i.e. the subject either received the certain amount or the lottery in turn was played out (again by throwing a dice). Due to monetary constraints we could pay only 10% of farmers which were randomly selected by letting farmers draw lots. Payments were made in cash instantly.

Based on the choices observed in each scenario we estimate the risk-aversion parameter of a Constant-Relative-Risk-Aversion (CRRA) specification of an expected utility function (Andersen et al., 2006; Harrison et al., 2010). In the specification $U(y) = y^{(1-r)} / (1-r)$ we use *y* to denote lottery pay-out and *r* to denote the (constant) coefficient of relative risk aversion. Based on this function, indifference between the lotteries and the certain amount in the different scenarios corresponds to values of *r* in the range -1.40 and 6.32 for the questionnaire experiments, and -1.46 and 8.27 in the field experiments.

Farmers' life history

To infer since when farmers lived on their farm, we examined records of farm deeds from the Deed's Office of Namibia. For a given farm these records denote every transaction, reaching as far back in time as 1920, and include the transaction date, the transferred area and the names of transferors and transferees. Matching this information with survey information for those farmers who identified their farm allows us to identify these present farmers' names and for how long previous farm owners shared the same surname. This in turn allows us to infer since when the respective farm was in family possession.[6] Comparing the year since when a farm was in family possession with the year of birth of the present farmer, we can infer whether the farmer grew up on his farm or whether he acquired it at some later stage.

Precipitation data

Actual precipitation data from the Namibia Meteorological Service is available for the period 1913–2008. However, these data are collected at only few weather stations across Namibia and the time series has many gaps. Instead, we use simulated precipitation data for our analysis. This data was generated by the three-dimensional, hydrostatic atmospheric circulation model REMO (REgional MOdel) (Jacob and Podzun, 1997; Jacob, 2001). The model is forced at the lateral boundaries with historical climate data and with output from the global climate model ECHAM4 (Roeckner et al., 1996) every six simulated hours. REMO

[6] There is a chance that transferors and transferees share the same surname even though they are not related. However, diversity of surnames among Namibian cattle farmers is high. Even when considering the most common surnames, there are never more than 19 individuals per surname in our survey population. Given the size of the survey population (1,916 farmers), the chance of transferor and transferee sharing the same surname even though they are not related is less than 1%.

data is available for the period 1978–2008. We use output data of REMO with a temporal resolution of six hours and a spatial resolution of 18km * 18km to calculate total precipitation per rainy season (November till April) for individual farms as a weighted mean over nine adjacent model gridboxes. This simulated data closely conforms to actual precipitation data in respect to the precipitation risk measure we employ. We discuss this at greater length in Section 3.3 where we detail the risk measure.

Input and output price data

Prices for inputs are temporally variable, but homogenous across farmers since all commercial farmers essentially trade with the same companies. Farmers produce two main outputs which are cattle sold to the slaughterhouse for meat production and cattle sold at auctions for further rearing by other farmers. Prices for the first output are also homogenous across farmers for the same reason cited under input prices.[7] We thus will not consider price risks of inputs and of cattle sold to the slaughterhouse as they may not explain individual differences in behavior.

In contrast, output prices for cattle sales at local auction may be spatially heterogeneous and this also across farmers since cattle are typically sold at auctions close to the farm. To examine this risk, we obtained price data for cattle sales on 2,083 commercial auctions across Namibia for the period 2000–2008 from Agra Co-operative Ltd, the largest retailer for farm equipment in Namibia and organizer of almost all cattle auctions. Data contain the location of auctions, the auction date, the number of sold cattle with average weight and average price per head and per kilogram.

3.2 Confounding influence of precipitation and price risk as background risks

In the risk experiments it was not feasible to elicit farmer’s risk preferences by experimentally varying precipitation risk, our primary risk of interest. We were therefore relegated to introduce an additional, artificial risk in the experiments and to examine endogeneity of preferences and self-selection in respect to precipitation risk by way of controlling for these two mechanisms. The downside of this approach is that it induces precipitation risk to constrain choices in the risk experiment by acting as a background risk. Thus, we now simultaneously deal with three mechanisms by which precipitation risk may act on risk preferences: endogeneity of preferences, self-selection and background risk. In addition to

[7] Inputs are purchased from Agra Co-operative Ltd. as well as from a few companies who distribute specialized products (de Bryn et al., 2007). All these companies have nationally homogeneous prices. In regards to outputs, 95% of cattle sold to the slaughterhouse are sold to MeatCo in the 2007, the latest available record (MAWF, 2009).

precipitation risk, farmers also face a cattle price risk which likewise acts as a background risk to choices in the risk experiment.

The background risks may thereby counfound our inferences on the occurrence of endogeneity of preferences and self-selection. To better pinpoint confounding influences we propose the following two-stage process in which the different mechanisms may act:

- first stage, *before* the risk experiments:

  i) endogeneity of preferences where precipitation risk form risk preferences contingent on life history

  ii) self-selection where farmers sort themselves, *ceteris paribus*, into local precipitation risk according to their risk preferences, and

- second stage, *in* the risk experiments:

  iii) precipitation background risk where the previously chosen local precipitation risk now acts as a constraint to choices in experiment with the artificial risk

  iv) price background risk where the local cattle price risk acts as an additional constraint

We will be able to adequately control for endogeneity of preferences with respect to precipitation risk by examining different subpopulations (methodically resolved by an interaction effect, cf. Section 3.3). Statements about this mechanism will therefore not be confounded by the presence of precipitation background risk. However, we cannot separately control for self-selection and precipitation background risk since the relevant variable, local precipitation risk, measures both mechanisms simultaneously. Thus, the measure of risk aversion we elicited is in this respect not a “pure” preferences parameter but instead a preferences parameter plus a confounding influence of the background risk constraint.

Does such a confounding influence of precipitation background risk preclude an interpretation of the relationship between risk preferences and risk as being the result of self-selection? Theoretical (Eeckhoudt et al., 1996), experimental (Harrison et al., 2007b) and field findings (Guiso and Paiella, 2008) suggest a positive relationship between risk aversion and background risk, at least when utility functions are characterized by non-increasing prudence, as is the case for constant relative risk aversion (CRRA) or constant absolute risk aversion (CARA) utility functions. If this holds indeed, the impact of background risk on risk aversion is of opposite sign to the proposed negative impact of self-selection (Guiso and Paiella, 2008; Jaeger et al., 2010). Assuming these relationships to also hold for our study, a *positive* impact of local precipitation risk on risk aversion would then indicate a background risk mechanism with an unclear contribution of self-selection while a *negative* impact would indicate self-selection with an unclear contribution of background risk. Thus, while it is impossible in our experimental setup to make statements on both self-selection and background risk simultaneously, we may – contingent on finding a significant non-zero impact – make at least unambiguous statements in respect to one of these mechanisms.

In regards to the price background risk of cattle sold at auctions we find that prices between auction locations are highly correlated with Pearson correlation coefficients being no smaller than 0.97 and significant at the 0.1%-level for correlation between any two locations.[8] Thus, this price background risk is effectively identical for all farmers. Similar to prices for inputs and cattle sold to the slaughterhouse it may not explain individual differences in behavior, and we do not consider in the further course of the paper.

3.3 Statistical specification

Risk measure

We employ the definition of risk developed by Rothschild and Stiglitz (1970) where a given distribution in precipitation is more risky in respect to another distribution if it is a mean preserving spread of said latter distribution. If distributions are log-normal, a mean-preserving spread is equivalent to a higher coefficient of variation (CV) for a given mean (Levy, 2006).

Rainfall in Namibia is log-normally distributed (Sandford, 1982).[9] To measure precipitation risk, we employ the inter-annual coefficient of variation (CV) of total rainy season precipitation while controlling for the inter-annual mean of total rainy season precipitation. Thus, if the CV of rainfall is higher on farm A than on farm B, where mean rainfall is the same, precipitation on farm A is more risky as the distribution can be described by a mean-preserving spread of the distribution of rainfall on farm B. Analytically, this translates into precipitation risk being measured by the CV while controlling for the mean with a riskier distribution being characterized by a higher CV for a given mean.

We calculate the inter-annual CV and mean of total rainy season precipitation for individual farms from REMO data. Furthermore, as we are interested in the precipitation risk that

[8] The reason is that a small number of buyers purchase the majority of cattle sold on auctions (Schutz, 2010).

[9] We also tested all distributions of total rainy season precipitation that were simulated by the REMO model and that we use in our analysis for log-normality using the Shapiro-Wilk-W test. The hypothesis of log-normality cannot be rejected for the vast majority (95 out of 99) of distributions at the 5%-level. We thus treated all distributions as log-normal.

individual farmers have experienced we only use the precipitation data of the period that a given farmer was present on the farm for the calculation of the risk. For some farmers this period is longer than the period of 1978–2008 for which REMO data is available. However, the precipitation risk over this longer period is well approximated by the risk over the period 1978–2008, and we use the risk measure calculated for the period 1978-2008 as a proxy for the risk of all longer periods.[10] Since CV estimates fluctuate wildly if based on only few observations we require that farmers lived on their farm for at least three years prior to the survey in order to be included in the analysis. We limit our analysis to risk-averse individuals and the risk measure is thus available for all farmers that are risk-averse, indicated their farm location and lived on the farm for at least three years.

Finally, we validate risk measures calculated from simulated data with the corresponding risk measures calculated from actual data by matching REMO data with data for the nearest weather station of the Namibia Meteorological Service (requiring a distance of less than 5km). Measures are highly correlated between both data sets and significant at the 0.1%-level, with a Pearson correlation coefficient of 0.76 ($p<0.001$, $n = 26$) and 0.74 ($p<0.001$, $n = 26$) for CV and mean, respectively. We thus conclude that simulated data closely conform to actual precipitation data in respect to our risk measure.

Socio-demographics, experimental type and life history

We control for various socio-demographic variables: gender, education (no college or apprenticeship education), area of rangeland (as a proxy for wealth), ownership structure (farm owned by multiple individuals, e.g. by corporations, cooperatives or trusts), living on farm (as a proxy for full-time farming versus part-time farming) and liquidity constraint (measured as the importance of loans for farm business operation, where more reliance on loans implies more liquidity constraint).[11] We represent life history by a continuous variable that denotes the number of years farmers have spent on their farm prior to adulthood, i.e. prior

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[10] We exemplarily analyzed actual rainfall data from the Namibia Meteorological Service to investigate how closely the risk measure derived from the period 1978–2008 conforms to the measure derived from the period 1930 (the year of birth of the oldest farmer included in our analyses) –2008. We chose all those stations for which at least 10 observations for total rainy season precipitation were available in both the periods 1930–1978 and 1978–2008, which applies to 79 stations, and calculate the respective risk measures. Pearson correlation coefficients are 0.93 ($p<0.001$) and 0.98 ($p<0.001$) for the CV and mean, respectively. We conclude that the risk measure derived from the period 1978–2008 can serve as a proxy for the risk measure of the period 1930–2008 as well as for all other periods Z –2008 where Z is an integer in the interval [1930, 1978].

[11] Two commonly used socio-demographic control variables, age and ethnicity, are not included in our analyses. We ran specifications with these variables but found that they were not significant and that their inclusion did not change our results. In order to avoid over-specification we tried to use as few control variables as possible and consequently excluded both age and ethnicity.

to age 18 years.[12] The idea behind this approach is that we may indicate how long farmers could have experienced the precipitation risk on their farm during childhood and adolescence. Finally, we also include an experimental control variable (questionnaire versus field experiments). Table 2 lists the respective variables with sample means, standard deviation and range.

Maximum likelihood specification

In our econometric specification of the expected utility function we follow the approach applied in previous studies in semi-arid areas by (Harrison et al., 2010) and which is detailed in (Harrison, 2008). The expected utility of the lottery, i.e. the auction in the questionnaire experiments and simply the lottery in the field experiments, is defined as

$$EU^L = p_1 U(y_1) + p_2 U(y_2) \tag{3}$$

where p_1 and y_1 denote the probability and payoff for outcome 1, p_2 and y_2 denote probability and payoff for outcome 2. Since probabilities and incomes were the same for all scenarios, it follows for the questionnaire experiments that

$$EU^L = 0.5\ U(N\$90,000) + 0.5\ U(N\$130,000) \tag{4}$$

and for the field experiments that

$$EU^L = 0.5\ U(N\$500) + 0.5\ U(N\$2,500)\ . \tag{5}$$

The expected utility for income from the certain amount is defined accordingly. Since this income is certain, the expected utility function reduces to $EU^C_i = U(y_{ci})$ where y_{ci} is the certain income for scenario *i* from the trader in the questionnaire experiments and the certain payout in the field experiments, respectively. Here, *i* as an index for the scenario (i=1,…,6 in the questionnaire experiment and i=1,…,16 in the field experiment).

We think of individuals as assessing the difference between expected utility derived from the lottery and the utility derived from the certain payoff when making their choices. They may, however, perform a processing error when evaluating the alternatives. This error can be specified as a Fechner error ε which is an additive error term that is normally distributed with mean zero and standard deviation σ (Fechner, 1860/1966; Hey and Orme, 1994; Loomes and Sugden, 1995). The EU difference the individuals evaluate is then

$$\Delta EU_i = EU^L - EU^C_i + \varepsilon\ . \tag{6}$$

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[12] We assume that farmers stayed on the farm ever since it came into family possession or since he acquired it.

Employing maximum likelihood estimation, we estimate the constant relative risk aversion (CRRA)-coefficient r and the Fechner error's standard deviation σ as parameters of a log-likelihood function.[13] This estimation assumes a cumulative standard normal distribution Φ defined over EU difference for the observed choices in each scenario. Thus, the log-likelihood function, conditional on the expected utility model and our CRRA specification being true, as well as on the observed choices, is

$$\ln L^{EUT}(r,\sigma;z,X) = \sum_i \left[(\ln(\Phi(\frac{\Delta EU}{\sigma})) \mid z_i = 1) + (\ln(1-\Phi(\frac{\Delta EU}{\sigma})) \mid z_i = 0) \right] \quad (7)$$

where $z_i = 1$ (0) denotes whether the subject choses the lottery (certain income) in scenario i and X is a vector of determinants. Due to an experimental artifact (many farmers indicated extreme responses) we did not include the responses of all farmers in the analysis. This artifact and our process of exclusion are described in detail in Appendix A.2.

We model r as a linear function of the determinants and assume that σ is influenced by gender. We may then analyze the hypothesis that precipitation risk influences farmers differently contingent on life history through an interaction effect between risk and life history. The estimate $\hat{r}$ of r is

$$\hat{r} = \hat{r}_o + \hat{r}_{MEAN} \cdot MEAN + \hat{r}_{CV} \cdot CV + \hat{r}_{YFPA18} \cdot YFPA18 + \hat{r}_{CV \times YFPA18} \cdot (CV \times YFPA18) + \hat{r}_X \cdot X \quad (8)$$

where *MEAN* is the inter-annual mean of total rainy season precipitation, *CV* the respective coefficient of variation which captures the precipitation risk, *YFPA18* the continuous life history variable denoting the number of years spent on the present farm prior to age 18 years, *CV* x *YFPA18* the interaction between risk and life history, and *X* a vector of control variables (see Table 2). We are interested in the value not only of the coefficients, but also of the constant $\hat{r}_o$. In order to interpret it as the CRRA of the "typical" farmer (contingent on the chosen independent variables) we define binary variables in such way that the value zero indicates the most frequent category. We redefine continuous independent variables by subtracting their respective means. Thus, for redefined continuous variables the value zero now represents the sample average. We did not redefine the life history variable because the

[13] Harrison et al. (2007b) discuss in detail why the estimation of the Fechner error reduces to estimating σ.

value zero is of special importance as it indicates those farmers who did not grow up on their farm.[14]

Finally, we assume that a farmer's responses in different scenarios are correlated, i.e. that the choice in one scenario is not independent of those in the other scenarios. We thus correct the standard errors by clustering all the responses for a single farmer. By doing so we effectively create a panel which is stratified by farmers.

4. Results

We present our results in the form of three different model specifications which employ samples of different sizes and composition (Table 3). Specification (1) includes only the socio-demographic and experimental control variables, but not the risk and life history variables. The sample for this specification consists of 1868 choices by 210 farmers. Specification (2) additionally includes the risk and life history variables, and Specification (3) the interaction effect between both variables. The sample for the latter two specifications is restricted to 994 choices by 99 farmers since we exclude farmers that were not risk-averse, did not reveal their farm location, lived on the farm for fewer than three years, or for whom we could not identified since when they lived on their present farm. We begin our discussion with findings on the causal mechanisms between risk preferences and precipitation risk, proceed with findings on the impact of socio-demographic and experiment control variables and close with robustness checks.

4.1 Causal mechanisms between risk preferences and precipitation risk

Both Specifications (2) and (3) indicate that risk preferences are significantly related to local precipitation risk. Specification (3), which we will discuss unless otherwise noted, indicates that the relationship is additionally contingent on life history: the total effect of risk on risk aversion constitutes of a significant main effect of risk and a significant interaction effect between risk and life history. The main effect is negative, with CRRA decreasing by 0.732 per unit of inter-annual CV of total rainy season precipitation. The interaction effect is positive where each year spent on the farm prior to age 18 years increases the total effect of risk on CRRA by 0.081. While it does not concern the relationship between risk preferences and risk, we note for completeness sake that the main effect of life history on risk aversion is

[14] If we define the life history variable in such a way, then the interaction effect between risk and life history is likewise zero for farmers who did not grow up on the farm. We will use this property in the discussion of our results (cf. Section 4.1).

small but likewise significant, with CRRA decreasing by 0.003 for each year spent on the farm prior to age 18 years.

To examine which causal mechanisms are at play it is helpful to discriminate between two subpopulations of farmers. The first subpopulation consists of farmers who did not grow up on their farm, i.e. who came to the farm as adults. For them, the total effect equals the main effect as *YFPA18* is zero (i.e. they have spent no year on their farm prior to age 18 years) and consequently also the interaction effect. These farmers are *less* risk averse under higher precipitation risk. The second subpopulation consist of farmers who grew up on their farm for at least one year prior to age 18 years and for whom *YFPA18* and the interaction effect are positive. For them, the total effect is less negative than the main effect as the positive interaction effect (partly) offsets the negative main effect. For a given precipitation risk, those farmers are more risk averse than farmers who did not grow up on their farm, and the shift towards risk aversion is larger the longer they have experienced the risk during childhood and adolescence. For farmers of this second subpopulation who have spent less than 10 years on their farm prior to age 18 years, the total effect remains negative as the interaction effect offsets the main effect only partially. They are still less risk averse under higher precipitation risk. In contrast, for farmers of who have spent (at least) 10 years on their farm prior to age 18 years the total effect becomes positive: the interaction effect then amounts to (at least) 0.81 and completely offsets the main effect of -0.732. They are *more* risk averse under higher precipitation risk.

Endogeneity of risk preferences

We hypothesize in Section 2.1 that risk preferences are endogenous with respect to precipitation risk experienced during childhood and adolescence and that formation of preferences is stronger the longer farmers have experienced this risk. We have no information on early-life experience of risk for the first subpopulation of farmers who did not grow up on their farm. However, we do have such information for the second subpopulation of farmers who grew up on their farms as they have already experienced the present risk. For them, our estimation results support our hypothesis: the interaction effect is non-zero and the total effect of risk on risk aversion consequently contingent on *YFPA18*. Thus, the relationship between risk preferences and risk changes with experiences of this risk during childhood and adolescence, and the change is more profound the longer this risk was experienced.[15]

[15] We exclude the possibility of reverse causality, i.e. risk aversion impacting on precipitation risk as precipitation is exogenous to the actions of the individual farmer during his lifetime.

We may interpret the positive sign of the interaction effect, i.e. that risk aversion is increasing with early-life experience of a risk, as a more general indication that experience with adverse conditions results in more risk averse behavior. In this regard, our observations are in line with those of Malmendier and Nagel (2011) who observe more risk averse behavior for stock and bond market investors who have experienced worse macro-economic conditions. We differ from their study in our interpretation of the results. Malmendier and Nagel (2011) propose endogeneity of risk beliefs as the causal mechanism. In contrast, we assume that farmers' subjective beliefs about the precipitation distributions conform to the objective distribution. Thus, we rule out endogeneity of beliefs as a possible explanation and instead propose endogeneity of risk preferences.[16] However, our results do not conform to those by Voors et al. (2011) who find that adverse experience of civil war shocks makes people more risk averse.

Self-selection

Based on the farm market model we formulate in Equations (1) and (2) we hypothesize that farmers self-select themselves according to risk preferences with more risk averse farmers operating on less risky farms. Our estimation results for the first subpopulation of farmers who did not grow up on their farm support this hypothesis: the total effect is negative and equal to the main effect of -0.732. Thus, within this subpopulation farmers are indeed less risk averse under higher precipitation risk. This results also conforms to previous findings, e.g. on choice of occupations with risky income (e.g. Bellemare and Shearer, 2010) or investment portfolios (e.g. Guiso and Paiella, 2005), that explained an observed negative relationship between risk aversion and riskiness of prospects by self-selection.

Precipitation background risk

Finally, we note in Section 3.2 that precipitation risk may act as a background risk. In contrast to endogeneity of preferences, we cannot control for this separately. The main effect of risk on risk aversion may thus reflect *both* self-selection and precipitation risk acting as a background risk. We therefore have to consider whether precipitation background risk may confound our findings on self-selection.

Consider three cases. In the first case, precipitation risk does not act as a background risk. Then our estimate of -0.732 for the main effect solely reflects self-selection. In the second

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[16] Similarly, even though Malmendier and Nagel (2011) propose endogeneity of beliefs as the underlying mechanism, they cannot rule out the possibility of endogeneity of preferences occurring simultaneously.

case, precipitation risk acts as a background risk and impacts positively on risk aversion, i.e. in the opposite direction of self-selection. Then we can only estimate a negative coefficient for the main effect if the positive effect due to precipitation background risk is completely offset by a considerably larger and negative effect due to self-selection. In the third case, precipitation risk again acts as a background risk but now impacts negatively on risk aversion, i.e. in the same direction as self-selection. Then we can make no statement on whether only self-selection, only background risk, both or neither are causal mechanisms that explain the negative impact of risk on risk aversion.

Based on previous literature findings (cf. Section 3.2), we can exclude the third case. That still leaves the first two cases and it is not possible to state which of either is true. We therefore cannot make any statement on whether precipitation risk is indeed acting as a background risk. However, we can state that the observed negative relationship between risk aversion and risk is at least partly due to self-selection. Thus, contingent on literature findings being true, the possibility of precipitation risk acting as a background risk does not confound our findings on self-selection.

Price background risks and liquidity constraint

Finally, we note that our results are neither confounded by price background risks or by liquidity constraint. As aforementioned, the price risks are homogenous across farmers and cannot explain individual differences in behavior. Liquidity constraint is heterogeneous across famers but do not impact on risk aversion as the coefficient is with -0.005 small and not significant.

4.2 Constant, socio-demographic and experimental control variables

Results on the socio-demographic and experimental control variables are identical in regards to sign and similar in regards to magnitude and significance for Specifications (2) and (3) All estimates that are significant in Specification (1) are also significant in Specifications (2) and (3), but absolute values of the constant and almost all variables are higher in the latter two specifications. At least for the constant, this is due to exclusion of risk attracted farmers. Finally, gender is significant only in Specifications (2) and (3). In the further course, unless otherwise noted, we will discuss the constant and control variables exemplarily for Specification (1).

We find that the “typical” farmer is risk-averse with a CRRA-coefficient of 0.975 (Table 3). This value is close to the 0.951 reported for field experiments with American coin collectors by Harrison et al. (2007b) who employ the same utility function and error specification. The Fechner error is not significant and only marginally different from zero. If we rerun the analysis without independent variables and error specification, we estimate a CRRA-coefficient of 0.779 (1950 choices by 221 farmers, p<0.001).[17] Thus, risk aversion for the "typical" farmer is confirmed over alternative model specifications, and this agrees with findings from other studies in semi-arid areas, such as Binswanger (1980) for India, Nielsen (2001) for Madagascar, Wik et al. (2004) for Zambia, Bezabih (2009) for Ethiopia, Yesuf and Bluffstone (2009) for Ethiopia and Harrison et al. (2010) for Ethiopia, India and Uganda).

Specifications (2) and (3), but not Specification (1), show that female farmers are less risk averse than male farmers with CRRA being lower by 0.313 and 0.342, respectively. This result echoes what Harrison et al. (2010) found in India, Uganda and Ethiopia, but is at odds with other results from semi-arid regions (e.g. Wik et al., 2004). Low education is positively related to risk aversion with an increase in CRRA by 0.04, and these findings are in accordance with, for example, Binswanger (1980). Farmers who operate in some form of joint ownership are with 0.024 units CRRA significantly less risk averse than farmers who are single owners. Area of rangeland is not related to risk aversion which is in contrast to Yesuf and Bluffstone (2009) who find a negative relationship. Likewise, part-time farming and liquidity constraint do not significantly affects risk aversion. Altogether, comparing the relationship between risk preferences and socio-demographic variables across studies does not reveal a clear picture on the sign of many of these variables. Our findings are thus best viewed in the specific context of commercial cattle farming in Namibia.

Turing to the experimental control variable we find that choices in field experiments (which involve real payouts) are associated with an increase in risk aversion by 0.395. One possible explanation for this difference is the payout level, which was almost 75 times higher in field experiments than in questionnaire experiments. This would imply globally decreasing relative risk-aversion (DRRA) in contradiction to our CRRA assumption. However, the observed difference in risk aversion may also be due to payout structure, i.e. real payouts in field experiments and hypothetical payouts in questionnaire experiments, or framing, i.e. the number of scenarios, elicitation procedure and the specific context in which the experiments were phrased. In regards to payout structure, Holt and Laudry (2002) reported subjects

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[17] This coefficient is higher than values reported from other field studies that assume the same utility function and no error specification, but not out of range of values that can be found in laboratory experiments. For example, Harrison et al. (2010) find a CRRA-coefficient of 0.536 in a field study in India, Uganda and Ethiopia, and Harrison et al. (2007a) a coefficient of 0.67 in a field study in Denmark, while Andersen et al. (2006) reported a value of 0.79 for laboratory experiments in Denmark.

behaved more risk-averse when confronted with real instead of hypothetical payouts. In regards to framing, Harrison et al. (2007b) found the CRRA-estimate differs by up to 0.756 across frames. In the light of this finding, the difference between CRRA between field and questionnaire experiments is reasonably small. Altogether, our finding that the CRRA-coefficient is sensitive to experimental type is unsurprising, but the exact reason remains elusive since our experiments were not designed to clarify this aspect. We maintain the assumption that CRRA holds at least locally for a given income domain. Both lab and field studies have shown this to be a plausible assumption (e.g. Holt and Laury, 2002; Harrison et al., 2007a).

4.3 Robustness check

In order to ensure that our results in Section 4.1 are not driven by certain assumptions or model specifications we perform robustness checks. We briefly summarize these checks here while we treat them at length in Appendix A.3 and A.4.

Life history as a binary variable

Our results on endogeneity of preferences may depend on the way we code life history. In this robustness check (Appendix A.3), we code life history not as a continuous variable as in Specification (3), but instead as a binary variable that indicates whether farmers were present on their farm at a certain threshold age. We estimate three separate specifications in which we vary the threshold age. In the first, we set the threshold to age 0 years. The binary variable then indicates whether farmers were born on their farm. In the second and third we set the threshold to age 9 years and age 18 years, respectively, to indicate farmers who lived already on their farm at age 9 years and 18 years.

Estimating these alternative specification we find that the main effect of risk on risk aversion is negative, while the interaction effect is positive and increases if farmers have spent more time on their farm during childhood and adolescence (i.e. if we lower the age threshold in the binary life history variable). Thus, using these alternative specifications we again find evidence for endogeneity of preferences and self-selection acting as causal mechanisms.

Heterogeneous time preferences

According to the farm market model in Equations (1) and (2) time preference in the form of a discount rate influences the bids farmers are willing to offer for a farm and thus ultimately self-selection onto farms. We assume in the previous analysis that time preferences are homogenous across farmers. However, we elicited time preferences along with risk preferences in the survey. We did not include them before due to an experimental artifact akin to what we described for risk experiments in Appendix A.2 which invalidates elicited data from time experiments for 32% of farmers. As a consequence, if we control for time preferences the number of farmers over which results are estimated decreases to only 79.

In this robustness check we include time preference as an additive control variable in the form of a time preference index (Appendix A.4). Estimation yields qualitatively the same results as in Specification (3): coefficients remain in the same order of magnitude and retain the sign, and significant (insignificant) coefficients remain significant (insignificant). The index itself is significant at the 1%-level and has a coefficient of -0.027. Thus, the parsimonious model we estimate in Specification (3) adequately captures the relationship between risk preferences and risk.

5. Discussion and conclusion

We find evidence that suggests that more risk averse farmers operate less risky farms. We have shown that this finding may be explained by a farm market that allocates farms to farmers according to their risk preferences. Even for farmers who never purchased a farm (i.e. who grew up on their farm) we observe evidence suggesting self-selection. More importantly, our analysis also shows that risk preferences endogenously depend on early-life experience with environmental risk. Finally, if early-life experience with environmental risk is long enough, endogeneity becomes the dominating mechanism for the relationship between risk preferences and risk. Our above results are robust to alternative model specifications and are not confounded by precipitation risk acting as a background risk, by price background risks or by liquidity constraint.

Our results have general implications since risk preferences play a fundamental role in economic theory. For example, Harsanyi (1953; 1955; 1977) justifies the Utilitarian social welfare function based on an argument where an impartial observer chooses social states behind a veil of ignorance according to von-Neumann-Morgenstern risk preferences. Endogeneity of risk preferences imposes an obvious challenge to this type of argument.

Our results also have specific implications for the management of ecosystems in the context of climate change. Climate change is considered to entail an increase in environmental risks, such as of fires, floods or droughts, which already affect many regions worldwide (Schneider et al., 2007). This alters peoples' opportunity sets and – given risk aversion – would, *ceteris paribus*, increase the demand for insurance against environmental risks. According to our results, however, an increase in experienced environmental risk might make future generations ever more risk averse which additionally increases insurance demand. Thus, development of well-functioning insurance markets in developing regions may become even more important in the coming decades.

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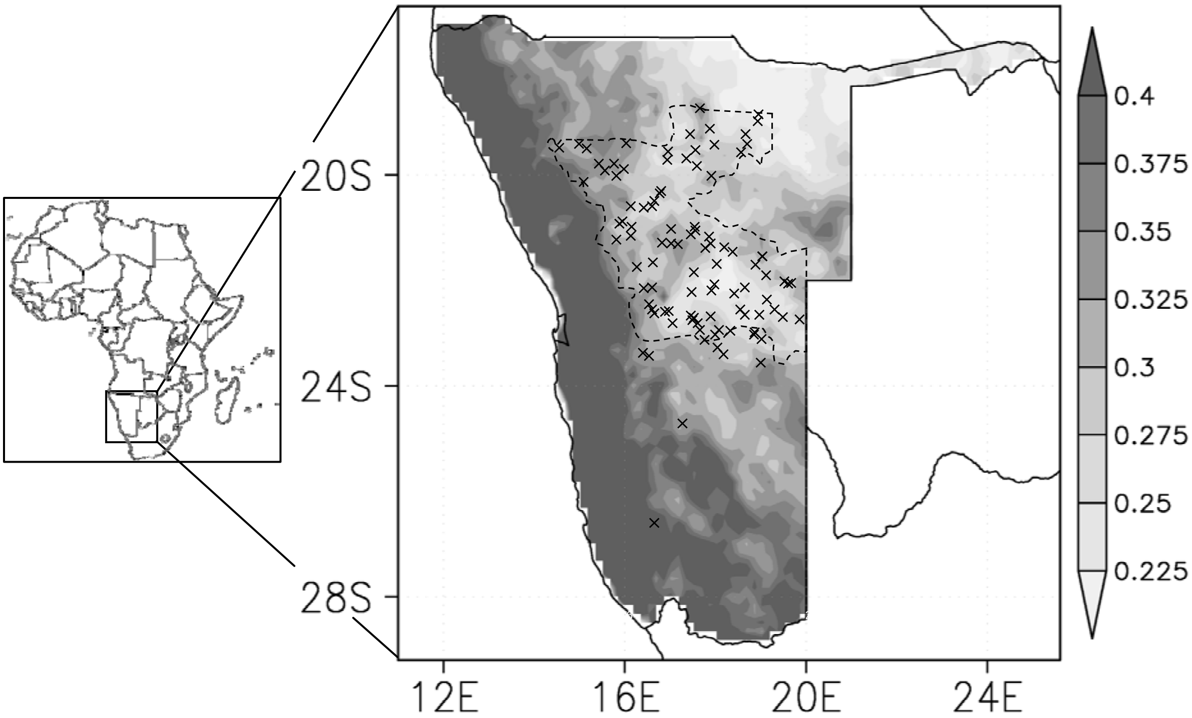

Figure 1: Precipitation risk in Namibia and study area. Shading denotes interannual coefficient of variation of total rainy season precipitation for the period 1978-2008, as calculated by the Regional Model (REMO). Crosses depict locations of those surveyed farms that were included in Specifications (2) and (3). Dashed lines indicates main commercial cattle farming area as adapted from Mendelsohn (2006), p. 43.

Table 1: Experimental design for risk preference elicitation: a) questionnaire experiments, b) field experiments.

a) Questionnaire experiments

Context provided in the questionnaire:

"In the following question, we would like you to respond to a hypothetical situation.

Let's assume you are forced to sell fifty weaners (due to financial or grazing reasons) and can do so at auction. However, you are uncertain about the amount of money they will fetch. You have a 50% chance that the fifty weaners combined will fetch N$ 90 000 and a 50% chance that they will fetch N$ 130 000.

Instead of selling at auction, you can sell the weaners to a reputable trader for a fixed amount of money. The trade procedures (i.e. driving to the venue, paperwork, etc.) are similar regardless of whether you sell at auction or to the trader.

For each of the following six scenarios, please choose whether you prefer to take part in the auction having a 50% chance of fetching either N$ 90 000 or N$ 130 000, or prefer to sell to the trader offering you increasing higher amounts of money.

➔ Please check only one box for each of the six scenarios."

Scenario	Lottery		Certain amount
	Outcome 1	**Outcome 2**	
1	N$ 90,000; ½	N$ 130,000; ½	N$ 100,000
2	N$ 90,000; ½	N$ 130,000; ½	N$ 102,500
3	N$ 90,000; ½	N$ 130,000; ½	N$ 105,000
4	N$ 90,000; ½	N$ 130,000; ½	N$ 107,500
5	N$ 90,000; ½	N$ 130,000; ½	N$ 110,000
6	N$ 90,000; ½	N$ 130,000; ½	N$ 112,500

b) Field experiments

No specific context provided.

Scenario	Lottery		Certain amount
	Outcome 1	**Outcome 2**	
1	N$ 500; ½	N$ 2,500; ½	N$ 550
2	N$ 500; ½	N$ 2,500; ½	N$ 600
3	N$ 500; ½	N$ 2,500; ½	N$ 650
4	N$ 500; ½	N$ 2,500; ½	N$ 700
5	N$ 500; ½	N$ 2,500; ½	N$ 800
6	N$ 500; ½	N$ 2,500; ½	N$ 900
7	N$ 500; ½	N$ 2,500; ½	N$ 1,000
8	N$ 500; ½	N$ 2,500; ½	N$ 1,100
9	N$ 500; ½	N$ 2,500; ½	N$ 1,200
10	N$ 500; ½	N$ 2,500; ½	N$ 1,300
11	N$ 500; ½	N$ 2,500; ½	N$ 1,400
12	N$ 500; ½	N$ 2,500; ½	N$ 1,500
13	N$ 500; ½	N$ 2,500; ½	N$ 1,600
14	N$ 500; ½	N$ 2,500; ½	N$ 1,700
15	N$ 500; ½	N$ 2,500; ½	N$ 1,800
16	N$ 500; ½	N$ 2,500; ½	N$ 1,900

Table 2: Variable list and descriptive statistics for Specifications (2) to (3). N = 99.

Variable	Definition	Sample mean	Standard deviation	Min	Max
Real payout	Participation in field experiment with real payout	0.25	0.44	0	1
Female	Female	0.04	0.20	0	1
Low education	No college or apprenticeship education	0.18	0.39	0	1
Area of rangeland	Area of rangeland in hectares	7,952	4,693	0	26,000
Multiple owners	Farm owned by a more than one individual	0.32	0.47	0	1
Living off-farm	Living off farm during the week, proxy for part-time farming	0.21	0.41	0	1
Liquidity constraint	Self-reported liquidity constraint, measured as importance of loans for farm business operation on a six-item Likert scale where higher values indicate more liquidity constraint	2.92	1.63	1	6
YFPA18	Number of years farmers have spent on their farm prior to age 18 years	8.19	8.56	0	18
Mean of precipitation	Inter-annual mean of total rainy season precipitation in mm	286.9	85.3	67.4	508.6
CV of precipitation	Inter-annual coefficient of variation (CV) of total rainy season precipitation	0.29	0.04	0.22	0.47
CV x YFPA18	Interaction effect between CV of precipitation and YFPA18	2.30	2.42	0	6.18

Table 3: Maximum likelihood estimation of coefficient of relative risk-aversion (r) and Fechner error (σ) for three different model specifications (1, 2, 3). Standard errors are reported in parentheses. Confidence levels: *** p<0.01, ** p<0.05, * p<0.1.

Parameter	Variable	(1)	(2)	(3)
r	Constant	0.975***	1.370***	1.382***
		(0.104)	(0.133)	(0.124)
	Real payout	0.395***	0.661***	0.672***
		(0.075)	(0.110)	(0.106)
	Female	0.070	–0.313***	–0.342***
		(0.067)	(0.115)	(0.116)
	Low education	0.040**	0.057**	0.069**
		(0.017)	(0.027)	(0.027)
	Area of rangeland	–0.000	0.000	0.000
		(0.000)	(0.000)	(0.000)
	Multiple owners	–0.024*	–0.059**	–0.067***
		(0.013)	(0.025)	(0.024)
	Living off-farm	–0.026	–0.048	–0.043
		(0.017)	(0.030)	(0.029)
	Liquidity constraint	0.001	–0.001	–0.005
		(0.004)	(0.006)	(0.006)
	YFPA18		–0.004**	–0.003**
			(0.001)	(0.001)
	Mean of precipitation		0.000	0.000
			(0.000)	(0.000)
	CV of precipitation		–0.492*	–0.732**
			(0.266)	(0.286)
	CV x YFPA18			0.081**
				(0.038)
σ	Female	–0.024	0.002	0.002
		(0.032)	(0.002)	(0.002)
	Constant	0.033	0.000	0.000
		(0.039)	(0.001)	(0.001)
	Log-likelihood	–659.2	–324.6	–321.4
	Chi-square	44.84	61.07	67.67
	Model significance	0.000	0.000	0.000
	Observations	1,868	994	994
	Clusters by individual	210	99	99

Appendix

A.1. Bids on the land market

The maximal constant fraction ϕ of annual income that a farmer with reservation utility

$$\int_0^\infty \frac{y_0^{1-r}}{1-r}\exp(-\delta t)dt = \frac{y_0^{1-r}}{1-r}\frac{1}{\delta}$$

is willing to bid is determined by the condition

$$\frac{\left((1-\phi)x_0\right)^{1-r}}{1-r}\frac{1}{\frac{1}{2}r(1-r)\sigma^2+\delta} = \frac{y_0^{1-r}}{1-r}\frac{1}{\delta}.$$

Solving for ϕ leads to (2).

Differentiating (2) with respect to r and σ, we obtain

$$\frac{d\phi^2}{drd\sigma} = -\frac{y_0}{x_0}\frac{\sigma}{\delta}\left(1+\frac{r(1-r)\sigma^2}{2\delta}\right)^{\frac{r}{1-r}-1}\cdot$$
$$\cdot\left(1+\frac{r(1-r)\sigma^2}{2\delta}+\frac{r^2(1-2r)\sigma^2}{(1-r)2\delta}+\frac{r}{(1-r)^2}\left(1+\frac{r(1-r)\sigma^2}{2\delta}\right)\ln\left(1+\frac{r(1-r)\sigma^2}{2\delta}\right)\right).$$

The expression in brackets is positive, as we shall prove in the following. We consider the cases $r>1$ and $r<1$ separately. For $r>1$, the third term is positive. The sum of the first two terms is positive by assumption $\frac{1}{2}r(1-r)\sigma^2+\delta>0$. The last term is positive by the same assumption. The sum of these positive terms must be positive as well. For $r<1$, we use

$$\ln\left(1+\frac{r(1-r)\sigma^2}{2\delta}\right) < \frac{r(1-r)\sigma^2}{2\delta}\left(1-\frac{1}{2}\frac{r(1-r)\sigma^2}{2\delta}\right)$$

which holds as by assumption $\frac{\sigma^2}{2}<\delta$. Hence, we have

$$\begin{aligned}
&\left(1+\frac{r(1-r)\sigma^2}{2\delta}+\frac{r^2(1-2r)\sigma^2}{(1-r)2\delta}+\frac{r}{(1-r)^2}\left(1+\frac{r(1-r)\sigma^2}{2\delta}\right)\ln\left(1+\frac{r(1-r)\sigma^2}{2\delta}\right)\right)\\
&<1+\frac{r(1-r)\sigma^2}{2\delta}+\frac{r^2(1-2r)\sigma^2}{(1-r)2\delta}+\frac{r^2\sigma^2}{(1-r)2\delta}\left(1+\frac{1}{2}\frac{r(1-r)\sigma^2}{2\delta}-\frac{1}{2}\left(\frac{r(1-r)\sigma^2}{2\delta}\right)^2\right)\\
&=1+\frac{\sigma^2}{2\delta}\left(r(1-r)+\frac{r^2(1-2r)}{1-r}+\frac{r^2}{1-r}\right)+\frac{r}{2}\left(\frac{r\sigma^2}{2\delta}\right)^2\left(1-\frac{r(1-r)\sigma^2}{2\delta}\right)\\
&=1+\frac{\sigma^2}{2\delta}\frac{r-2r^2+r^3+r^2-2r^3+r^2}{1-r}+\frac{r}{2}\left(\frac{r\sigma^2}{2\delta}\right)^2\left(1-\frac{r(1-r)\sigma^2}{2\delta}\right)\\
&=1+\frac{\sigma^2}{2\delta}\frac{r-r^3}{1-r}+\frac{r}{2}\left(\frac{r\sigma^2}{2\delta}\right)^2\left(1-\frac{r(1-r)\sigma^2}{2\delta}\right)>0
\end{aligned}$$

Overall, we have $\frac{d\phi^2}{drd\sigma} < 0$ which proves the proposition.

A.2 Elimination of experimental artifacts

About one quarter (23.4%) of farmers who mailed in questionnaires never or always chose the lottery in the questionnaire experiment, i.e. they made choices that characterize them as extremely risk averse or extremely risk attracted. Such a pattern was not apparent for those 39 farmers that completed the questionnaire experiment in the presence of a researcher (during our experimental sessions) where only 17.5% never or always chose the lottery. A two sample Kolmogorov-Smirnov test for equality of distributions reveal significant differences between both groups (p=0.032). In the sessions where a researcher was present we observed that it frequently took farmers a long time to complete the hypothetical risk experiment in the questionnaire. Furthermore, after having filled in the questionnaire some of those farmers who were characterized as extremely risk averse or extremely risk attracted remarked that they had a personal dislike for selling at auctions or to a trader, respectively.

Based on these observations, we consider the extreme responses of those farmers who mailed-in questionnaires likely to be experimental artifacts that do not reflect risk taking behavior. We therefore exclude these farmers in our analyses. After exclusion, a two sample Kolmogorov-Smirnov test is no longer significant (p=0.332). The above described maximum likelihood-estimation is thus at the tails defined only over responses from the 39 experimental participants for which we are certain that they indicated risk taking behavior.

A.3. Robustness check: life history as a binary variable

In Specification (3) we examine for endogeneity of risk preferences by coding life history as the continuous variable *YFPA18* and by calculating the interaction effect with precipitation risk. In this robustness check, we code life history as the binary variable *GREWUP* which indicates whether farmers lived already on their farm at a certain threshold age (*GREWUP* = 1) or not (*GREWUP* = 0). We then calculate the interaction effect between the precipitation risk farmers have experienced and *GREWUP* accordingly and estimate the model:

$$\hat{r} = \hat{r}_o + \hat{r}_{MEAN} \cdot MEAN + \hat{r}_{CV} \cdot CV + \hat{r}_{GrewUp} \cdot GREWUP + \hat{r}_{CV \times GrewUp} \cdot (CV \times GREWUP) + \hat{r}_X \cdot X \quad (9)$$

where *GREWUP* is the binary life history variable and *CV* × *GREWUP* the interaction effect between precipitation risk and life history. Estimation results obviously depend on the precise value we select for the threshold age of *GREWUP*. We exemplarily report below estimations for the three values 0, 9 and 18 years, but we arrive at the same qualitative results if we choose other values in the interval [0 years, 18 years]. Accordingly, in Specification (4) we set the threshold age to 0 years. *GrewUp* then indicates whether farmers were born on their farm. In Specification (5) and (6) we set the threshold to 9 years and 18 years, respectively, to indicate farmers who lived already on their farm at age 9 years and age 18 years.

Estimation results show that the main effect of risk on risk aversion is significant, negative and similar between Specifications (4) to (6) with a value between -0.531 and -0.718 (Table 4). The interaction effect is positive in all specifications, but significant only in the first two. Its value decreases from 1.696 to 1.303 and 0.360 in Specifications (4), (5) and (6), respectively.

These results confirm our previous findings on endogeneity of preferences. The positive interaction effect indicates that, for a given risk, farmers who grew up on their farm are more risk averse than those who did not grow up on their farm. Furthermore, the interaction effect is larger in magnitude the lower we set the age threshold, indicating that the relationship between risk aversion and risk is impacted on more strongly the longer farmers have experienced the risk. Finally, the interaction effect is no longer significant if we set the threshold age to 18 years, suggesting that risk must be experienced in early life in order to form preferences.

The results also confirm our finding on self-selection. For the subpopulation of farmers whom we designated as not having grown on their farm, i.e. for whom *GrewUp* and the interaction effect take on the value zero, the total effect of risk on risk aversion equals the negative main effect. In Specification (6), the composition of this subpopulation corresponds to that in Specification (3), i.e. comprises of farmers who came to the farm at age 18 years or old and thus presumably by their own choice. Thus, the negative relationship between risk aversion and risk suggests self-selection according to risk preferences. In Specification (5) and (4) the composition is different: farmers designated as not having grown up on their farm comprise all farmers who came to the farm of their own choice as well as those who came there with their parents between age 10 to 18 years and age 1 to 18 years, respectively. The negative relationship suggests self-selection even if farmers are included who never changed farms on their on choice.

Altogether, results in this alternative approach with a binary life history variable confirms our previous finding on endogeneity of preferences and self-selection that we estimated with a continuous life history variable. These previous findings are thus not sensitive to the concrete model specification we employed in Specification (3).

A.4. Robustness check: heterogeneous time preferences

Correspondingly to the elicitation of risk preferences, we elicited time preferences by a multiple price list format with hypothetical payouts, as detailed in Olbrich et al. (2009). In a context free frame, farmers had to choose in five scenarios between receiving a payment in one month or a higher payment in seven months. The payment in one month of N$100,000 was constant throughout all scenarios. The payment in seven months increased from N$104,881 in the first scenario, which corresponds to an annual interest rate with quarterly compounding of 10%, to N$122,474 in the fifth and last scenario, which corresponds to an interest rate of 50%. Values for later payments in the scenarios in between the first and the last were chosen in such a way that the corresponding interest rate increased by 10% per scenario.

In these kind of experiments, subjects typically prefer the earlier payment when the later payment is low and switch once the later payment is deemed high enough. Out of the switch point we constructed a time preference index as an integer variable with values in {1, 2, …, 6} where high values denote high impatience and thus imply a high discount rate, i.e. those farmers who only switch to the later amount when it is high. The highest possible value ‘6’ denotes very high impatience, i.e. those farmers who never switch to the later amount.

Including the time preference index as an additive control variable in regression Equation (8) yields the following augmented equation:

$$\hat{r} = \hat{r}_o + \hat{r}_{MEAN} \cdot MEAN + \hat{r}_{CV} \cdot CV + \hat{r}_{YFPA18} \cdot YFPA18 + \hat{r}_{CV \times YFPA18} \cdot (CV \times YFPA18) + \hat{r}_{TPI} \cdot TPI + \hat{r}_X \cdot X \quad (10)$$

where *TPI* is the time preference index. Including the index reduces the sample size to 874 choice from 79 farmers due to an experimental artifact akin to what we observed in the risk experiments (cf. Appendix A.2).

Estimating this regression as Specification (7) confirms our results in Specification (3): all coefficients remain in the same order of magnitude and retain the sign, and significant (insignificant) coefficients remain significant (insignificant) (Table 4). The time preference index itself is significant at the 1%-level and has a coefficient of -0.027. Thus, farmers who are less impatient (have a lower implied discount rate) are more risk averse. These findings on the time preference index conform to Anderson et al. (2008a) who study both risk and time preferences and who estimate a lower discount rate if they consider that experimental participants are risk averse instead of risk neutral. Altogether, control for time preferences does not change our findings on the relationship between risk preferences and precipitation risk, and the parsimonious model we estimated in Specification (3) thus captures adequately the relationship between risk preferences and environmental risk.

Table 4: Maximum likelihood estimation of expected utility model of choice. Specification (3) as in Table 3. Specification (4), (5) and (6) denote life history by the binary variable *GrewUp* with the age threshold set at 0 years, 9 years and 18 years, respectively. The interaction effects between life history and precipitation risk are calculated correspondingly. Specification (7) is as (3) but includes a time preference index. Standard errors are reported in parentheses. Confidence levels: *** p<0.01, ** p<0.05, * p<0.1.

Parameter	**Variable**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**
r	Constant	1.382***	1.378***	1.383***	1.362***	1.402***
		(0.124)	(0.126)	(0.127)	(0.148)	(0.154)
	Real payout	0.672***	0.671***	0.674***	0.650***	0.691***
		(0.106)	(0.107)	(0.108)	(0.119)	(0.133)
	Female	–0.342***	–0.323***	–0.347***	–0.301***	–0.327***
		(0.116)	(0.109)	(0.117)	(0.107)	(0.106)
	Low education	0.069**	0.065**	0.069**	0.052*	0.080***
		(0.027)	(0.026)	(0.027)	(0.028)	(0.025)
	Area of rangeland	0.000	0.000	0.000	–0.000	0.000
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
	Multiple owners	–0.067***	–0.065***	–0.065***	–0.053**	–0.043*
		(0.024)	(0.022)	(0.023)	(0.023)	(0.022)
	Living off-farm	–0.043	–0.058*	–0.034	–0.054*	–0.026
		(0.029)	(0.031)	(0.029)	(0.030)	(0.029)
	Liquidity constraint	–0.005	–0.004	–0.005	0.002	–0.006
		(0.006)	(0.006)	(0.006)	(0.006)	(0.005)
	YFPA18	–0.003**				–0.003***
		(0.001)				(0.001)
	GrewUp		–0.041	–0.053**	–0.029	
			(0.026)	(0.023)	(0.021)	
	Mean of precipitation	0.000	0.000	0.000	0.000	0.000
		(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
	CV of precipitation	–0.732**	–0.635**	–0.718**	–0.531*	–0.533**
		(0.286)	(0.277)	(0.281)	(0.285)	(0.252)
	CV x YFPA18	0.081**				0.110***
		(0.038)				(0.042)
	CV x GrewUp		1.696**	1.303**	0.360	
			(0.758)	(0.633)	(0.630)	
	Time preference index					–0.027***
						(0.008)
σ	Female	0.002	0.001	0.002	0.001	0.001
		(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
	Constant	0.000	0.000	0.000	0.000	0.000
		(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
	Log-likelihood	–321.4	–322.7	–321.5	–330.3	–293.4
	Chi-square	67.67	69.64	68.71	73.64	56.70
	Model significance	0.000	0.000	0.000	0.000	0.000
	Observations	994	994	994	994	874
	Cluster	99	99	99	99	79

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