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Investigating Climate Change Perception and Expectation Formation for the Advancement of Agent-Based Models Applied to Agricultural Adaptation Assessment

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Summary

To inform more realistic representations of farmer decision making in agent-based simulation models applied to agricultural adaptation assessment at the regional scale, the present thesis[1] investigates three areas of central importance for judgments about farm-level reactions to climate change: (i) perception of changes in local weather conditions and expectations about their effects; (ii) reception of signals from the biophysical environment and their interpretation in terms of socially constructed understandings of climate change, farm-level risks, and perceived adaptation capacity; and (iii) the nature of expectation mechanisms involved in the formation of judgments about climatic changes. For this purpose, three types of empirical approaches were used: questionnaire-based surveys conducted with farmers from two study areas in Southwest Germany, the Central Swabian Jura and the Kraichgau; a questionnaire-based comparative study of farmer school students and pre-first-semester undergraduate university students enrolled in study programs related to agriculture without experience in farming and no study-experience; and economic lab experiments conducted with farming practitioners (experienced farmers and farmer school students) and university students from agriculture-related study programs with several semesters of study experience.

Descriptive data analysis reveals that the majority of farmer respondents from the two study areas perceived a change in weather conditions at their location, an increase in weather variability, as well as a decreasing predictability of weather conditions, and expected consequences for their farming activities due to these developments. Four main factors are found to influence the perception of changes in local weather conditions: respondents' age, location of the farm, share of agricultural income of total household income and farm profit. Further, farmers' age, location of the farm, method of production, and farm size are found to be significant predictors for farm leaders' expectations about climate change effects. Word associations related to the term 'climate change' obtained from farmer school students and undergraduate university students reveal differences in socially constructed understandings of climate change: The young farming practitioners tended to conceptualize climate change in terms of personal experiences with their biophysical environment - predominantly with extreme weather conditions and warmer temperatures - whereas the unexperienced university students with no farming background employed representations that were associated with psychologically distant events, high levels of alert, and usually conveyed by the media.

Environmental outcomes interpreted as climate change effects and, especially, extreme weather events, contributed significantly to perceived farm-level risks. Their perceived relevance however appears to be influenced by developments in other fields of risk, e.g. recent changes in market conditions, agricultural policy decisions, and personal circumstances

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such as health concerns. Farmers from the research areas were found to conceptualize farm-level adaptation predominantly in terms of short-term adaptations that require minor adjustments of the production practice, such as cultivation of new crops and cultivars, changes in soil-, pesticide- and fertilizer management, as well as the need for increased machinery- and labor capacity during crucial times of the production cycle. Adaptation was found to be primarily understood in terms of reactions to a greater weather variability, an increased incidence of drought periods and warmer temperatures in general, and thus to be closely related to the elicited social representations farmers employed for climate change.

The applied experimental approach allowed to translate statistical information related to climate change into concrete experience with climate outcomes, and to observe expectation formation and dependent economic choices of participants, that were, in addition, financially incentivized. A specifically developed procedure enables to identify expectation mechanisms employed at the level of the individual participant, as well as the underlying heuristics. The approach reveals a great degree of heterogeneity in expectation formation among participants and finds patterns consistent with rationality, consistent with cognitive biases, and patterns that are inconsistent with either of these.

Based on these empirical findings, the following recommendations for the agent-based modeling software MPMAS are derived: (i) agent-specific levels of climate change awareness should be accounted for to reflect the effects of personal experiences with climate change outcomes, social norms and individual-specific learning patterns and coping behavior; (ii) the effects of incomplete information assessment and risk aversion should be reflected in the imputed selection mechanism for climate change response, i.e. for the choice of adaptation measures; and (iii) experimental results should be used to inform modeled expectation mechanisms of agents, currently implemented for judgments about future prices and yields.

Zusammenfassung

Um eine realistische Abbildung des Entscheidungsverhaltens von Landwirten in agentenbasierten Modellen für die Simulation der Anpassung des Landwirtschaftssektors an die Folgen des Klimawandels auf regionaler Ebene zu ermöglichen, beschäftigt sich diese Dissertation[2] mit drei Bereichen von zentraler Bedeutung für Entscheidungen zu Anpassungsmaßnahmen auf Betriebsebene: 1. Der Wahrnehmung von Veränderungen der lokalen Wetterbedingungen und den Erwartungen zu deren Auswirkungen; 2. Der Wahrnehmung von Signalen aus der biophysikalischen Umwelt und ihrer Interpretation in Form eines gesellschaftlich konstruierten Verständnisses von Klimawandel, Risiken auf Betriebsebene und wahrgenommener Anpassungsfähigkeit; und 3. Der Art von Erwartungsbildungsmechanismen die bei der Beurteilung klimatischer Veränderungen und deren Auswirkungen eine Rolle spielen. Für diese Zielsetzung wurden drei Arten von empirischen Verfahren angewandt: Fragebogenbasierte Erhebungen unter Landwirten aus zwei Untersuchungsregionen in Südwestdeutschland, der Zentralen Schwäbischen Alb und dem Kraichgau; eine fragebogenbasierte, vergleichende Studie zwischen landwirtschaftlichen Techniker- und Meisterschülern und Universitätsstudierenden aus Bachelorstudiengängen mit Agrarbezug, jedoch ohne landwirtschaftlichen Hintergrund und ohne Studienerfahrung; und ein computerbasierter, experimentalökonomischer Ansatz mit landwirtschaftlichen Praktikern (Landwirten, landwirtschaftlichen Techniker- und Meisterschülern) und Universitätsstudierenden aus Studiengängen mit Agrarbezug sowie mehreren Semestern Studienerfahrung.

Anhand deskriptiver Datenanalysen kann gezeigt werden, dass Landwirte aus den Untersuchungsregionen Veränderungen der Wetterbedingungen an ihren Standorten feststellten, dabei eine Zunahme der Wettervariabilität und eine abnehmende Einschätzbarkeit der Wetterbedingungen wahrnahmen, und aufgrund dieser Entwicklungen mit Folgen für ihre Betriebe rechneten. Vier Hauptfaktoren beeinflussten dabei die Wahrnehmung lokaler Wetterveränderungen: Das Alter der Teilnehmer, der Standort des Betriebs nach Region, die Art der Erzeugung (ökologisch/konventionell), der Anteil des landwirtschaftlichen Einkommens am Gesamteinkommen, und der Betriebsgewinn. Zudem erwiesen sich das Alter, der Standort des Betriebs, die Art der Erzeugung und die Betriebsgröße als signifikante Einflussfaktoren auf die Erwartungen der Betriebsleiter bezüglich der Effekte des Klimawandels auf ihren Betrieb.

Die von landwirtschaftlichen Techniker- und Meisterschülern und von Studierenden erhobenen Wortassoziationen mit dem Ausdruck 'Klimawandel' weisen auf Unterschiede im gesellschaftlich konstruierten Verständnis des Begriffes hin: Die jungen Landwirte neigten dazu, Klimawandel in Bezug auf persönliche Erfahrungen mit ihrer biophysikalischen Umwelt zu konzeptualisieren, vorwiegend mit dem Auftreten von Extremwetterereignissen und wärmeren Temperaturen, wohingegen die befragten Studierenden aus Studiengängen

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mit Agrarbezug jedoch ohne fachspezifischer Studienerfahrung und persönlichem landwirtschaftlichem Hintergrund sozial erzeugte Vorstellungen gebrauchten, die sich auf psychologisch ferne Ereignisse bezogen und mit einem hohen Grad an Alarmiertheit einhergingen und üblicherweise von Medien übertragen werden.

Umweltbedingungen, die teilweise als Effekte des Klimawandels interpretiert wurden und insbesondere extreme Witterungsereignisse machten einen großen Anteil der von Landwirten auf betrieblicher Ebene wahrgenommenen Risiken aus. Die aktuell empfundene Bedeutung dieser Art von Risiken scheint allerdings von Entwicklungen in anderen Risikobereichen abhängig zu sein, so zum Beispiel von aktuellen Veränderungen der Marktbedingungen, Entscheidungen in der Agrarpolitik, sowie von persönlichen Umständen, wie etwa Gesundheitsbedenken. Landwirte aus den Untersuchungsregionen konzeptualisierten Klimawandelanpassung auf Betriebsebene vorwiegend in Form kurzfristiger Anpassungsmaßnahmen die mit eher geringfügigeren Änderungen der üblichen Praxis einhergehen, wie etwa Änderungen bei der Bodenbearbeitung oder beim Spritzmittel- und Düngereinsatz, dem Anbau neuer Sorten und Kulturen, sowie in Form eines gestiegenen Bedarfs an Maschinen- und Arbeitskapazität während wichtiger Zeiten des Produktionszyklus. Klimawandelanpassung wurde überwiegend als Reaktion auf eine stärkere Wettervariabilität verstanden, auf ein erhöhtes Auftreten von Trockenperioden und wärmeren Temperaturen generell, und weist damit einen engen Bezug zu dem in der sozialen Gruppe der Landwirte erhobenen sozialen Konstrukt von Klimawandel auf.

Der angewendete experimentalökonomische Ansatz ermöglichte es, statistische Informationen zu Klimawandel in konkrete Erfahrungen mit den damit verbundenen Effekten zu überführen und gleichzeitig Erwartungsbildung und davon abhängiges, ökonomisches Entscheidungsverhalten zu beobachten, da diese Entscheidungen im Experiment mit einem finanziellen Anreiz verknüpft wurden. Ein eigens entwickeltes Verfahren erlaubt Mechanismen der Erwartungsbildung sowie die zugrundeliegenden Heuristiken auf der individuellen Ebene nachzuvollziehen. Der Ansatz deckt ein hohes Maß an Heterogenität bei Mechanismen individueller Erwartungsbildung auf und verweist auf Muster die konsistent sind mit rationaler Erwartungsbildung, mit kognitivem Bias unterschiedlicher Art, aber auch auf solche, die mit keinem der beiden Ansätze erklärbar sind.

Basierend auf diesen empirischen Erkenntnissen werden folgende Empfehlungen für die agentenbasierte Modellierungssoftware MPMAS abgeleitet: 1. Klimawandelbewusstsein sollte auf Ebene der Agenten abgebildet werden, um die Effekte persönlicher Erfahrungen mit Klimawandel, sozialer Normen und individueller Lern- und Bewältigungsstrategien abbilden zu können; 2. Die Effekte unvollständiger Informationsakquise und -verarbeitung sowie von Risikoaversion sollten im für Klimareaktionen (d.h. für die Wahl von Anpassungsmaßnahmen) angenommenen Entscheidungsmechanismus widergespiegelt werden; 3. Die mit dem experimentalökonomischen Ansatz gewonnen Erkenntnisse sollten verwendet werden, um die angenommenen Erwartungsbildungsmechanismen, die bisher für zukünftige Preise und Ernten explizit abgebildet sind, zu ergänzen.

Contents

List of Acronyms

ABM:	Agent-Based Model
CC:	Climate Change
GHG:	Greenhouse Gases
EUT:	Expected Utility Theory
LUCC:	Land Use and Land Cover Change
MAS	Multi-Agent System
MPMAS:	Mathematical Programming-based Multi-Agent Systems

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1 Introduction

Climate change is expected to profoundly alter farming conditions in many parts of the world. Farm survival and on a global scale, food security, will crucially depend on the capacity of farming businesses to adapt to the associated changes and, especially, on whether the speed of adaptation can keep up with the speed of change in climatic conditions (Rosenzweig & Tubiello, 2007). Recent scientific research has shown that adaptation to climate change in an economically efficient and objectively rational manner is hampered by a set of conditions summarized under the term 'social barriers', that exist in addition to technological, economic and ecological limitations (Adger et al., 2009; Lorenzoni, Nicholson-Cole, & Whitmarsh, 2007; Raymond & Spoehr, 2013). In combination, these limitations determine the adaptive capacity of agro-ecological systems and other areas of human activity. In broad terms, social barriers are defined as normative, cognitive and institutional obstacles to adaptation. While cognitive barriers are tied to the individual and result from how psychological and thought processes in the organism of a decision maker elapse, normative barriers are related to the interaction of the individual with the social environment: social constructs and cultural norms present in the social environment influence perception and response of individuals to climate change (Moloney et al., 2014; Raymond & Spoehr, 2013; Weber, 2010, 2016).

The present doctoral thesis attempts to contribute empirical insights into processes relevant for farmer decision making in this context and through that, to contribute to the improvement of climate change adaptation models, specifically to multi-agent system models of land-use and land-cover change (MAS/LUCC) applied for the assessment of adaptation pathways of the agricultural sector at the regional scale.

This PhD thesis is a contribution to the research project "Agricultural Landscapes under Global Climate Change - Processes and Feedbacks on a Regional Scale" (FOR 1695), that is conducted in a cooperation of the Helmholtz-Zentrum Munich, the Justus-Liebig-University Giessen and the University of Hohenheim, and funded by the Deutsche Forschungsgemeinschaft (DFG). The research project's stated aim is to increase the understanding of processes that shape structure and functions of agricultural landscapes in the context of climate change as well as their feedbacks into the climate system at a regional scale.

1.1 Problem statement and research motivation

Climate change adds to the uncertainty associated with agricultural production (Antle & Capalbo, 2010), and thus contributes importance to the understanding of processes involved in farmers' production and investment choices. Considering now widely recognized findings from the subfields of behavioral- and psychological economics, a massive body of evidence has accumulated for the finding that economic decision makers systematically violate many of the prepositions of traditional models of economic behavior. Weber (2010) has shown that in addition to the effects of social norms, the perception and processing of information on climate change is shaped by factors that are highly individual-specific, and further findings from cognitive science suggest that human judgment on climate related issues probably is even more subject to systematic failure than probability judgments in most other fields of economic decision making (Leiserowitz, 2006; Marx et al., 2007; Weber, 2006, 2010). Therefore (perceived) adaptive capacity, adaptation pathways chosen and resilience may be significantly heterogeneous within a farming population (Grothmann & Patt, 2005; Reidsma, Ewert, Lansink, & Leemans, 2010). Rather than comparative-static approaches that abstract from the heterogeneity of farm businesses and the sequential nature of many changes, dynamic models that are capable of capturing the heterogeneity of farm decision makers and farming conditions are necessary for assessing reactions to climate change and the adaptation pathways of agriculture in a certain region. Due to these various and very specific influences, it is especially essential for the simulation and evaluation of pathways of agricultural adaptation at the regional scale to understand and reflect how climate change related decision processes elapse in farm decision makers.

Sociologists and social psychologists have focused on the influence of social norms and resulting socially generated understandings of climate change for the readiness of humans to react (Lorenzoni et al., 2007; O’Neill & Nicholson-Cole, 2009), and have developed theories that explicitly account for these impacts (see, for instance Ajzen 1991). The influence of social norms depends on factors such as a person's belonging to a social group, individual values, beliefs and world-views, and the desire to comply with social rules and expectations (Schlüter et al., 2017), and are therefore highly individual- and context-specific.

Besides socially determined behavior, the expectation a farm decision maker holds about the effects of climate change at a given point in time determines the perceived need for adaptation, both with regard to yearly decisions, such as land allocation to crops, production schedules, farming practice and commercialization strategies, as well as with regard to long-term strategic decisions often involving investments (Antle & Capalbo, 2010; Bert, Satorre, Toranzo, & Podestá, 2006; Weber, 1997). While weather events can be observed and farm decision makers are expected to monitor weather outcomes closely, research has shown that fallacies that affect the perception of natural climate variability and its differentiation from the effects of climate change are widespread, and that scientific information that complements personal experience is only able to correct for that to a limited extent (Hansen, Marx, & Weber, 2004; Lybbert, Barrett, McPeak, & Luseno, 2007).

Due to the relatively long time lag between production decision and harvest, as well as the high volatility in yields and prices, understanding how farm decision makers form expectations has long been a question of crucial importance in agricultural production models (Nerlove, 1958). So far, agent-based mathematical programming models applied within the field of agricultural economics, have dealt with expectation formation mainly in the context of producer prices (Nolan, Parker, Van Kooten, & Berger, 2009). While many modelers simply used constant prices throughout simulations or assumed rational expectations and perfect foresight, those that explicitly modeled the process of expectation formation rely largely on variants of the adaptive expectations approach by Nerlove (1958) for modeling the development of price expectations (see, for instance, Berger 2001; Freeman et al. 2009; Happe et al. 2008; Schreinemachers et al. 2009). In most of these cases, the choice of how to include expectations probably was motivated by convenience and ease of implementation since expectation formation was more a necessary component to complete the model, rather than the focus of the model applications. A similar lack of attention for how expectations are assumed to be made and how they actually are formed is found and criticized by Just and Rausser (2002) for agricultural economics research in general.

In the context of climate change adaptation however, learning patterns and expectations held by decision makers constitute a central issue (Berger & Troost, 2014). Janssen and de Vries (1998) demonstrate this in a multi-agent framework for the reactions of international policy makers to climate change outcomes. In the light of the cited findings, a choice of the expectation formation mechanism neither based on empirical nor theoretical foundations is clearly unsatisfactory in the context of climate change adaptation assessment.

Given these research gaps, this thesis attempts to contribute to agricultural land-use and climate change adaptation research through explaining modes of individual-specific expectation formation, by generating context-specific empirical insights on the factors that determine expectation formation, and through developing hints for employing these empirical findings to inform representations of farm-level decision making implemented in agent-based models that are applied for the assessment of climate change effects at the regional scale.

1.2 Conceptualizing the cognitive process of adaptation

Nguyen et al. (2016) proposed the following framework to conceptualize the cognitive process of farmers' perception and adaptation to climate change (Figure 1). Sensory observations, i.e. the reception of signals from the biophysical and socioeconomic environment induce *learning* about potential changes in the environment. This information is then interpreted in the context of personal experiences, socioeconomic and socio-cultural backgrounds, motives, beliefs and socially constructed understandings, or, in alternative duct, in terms of social representations about abstract concepts such as risk or adaptive capacity, during the process of *understanding*.

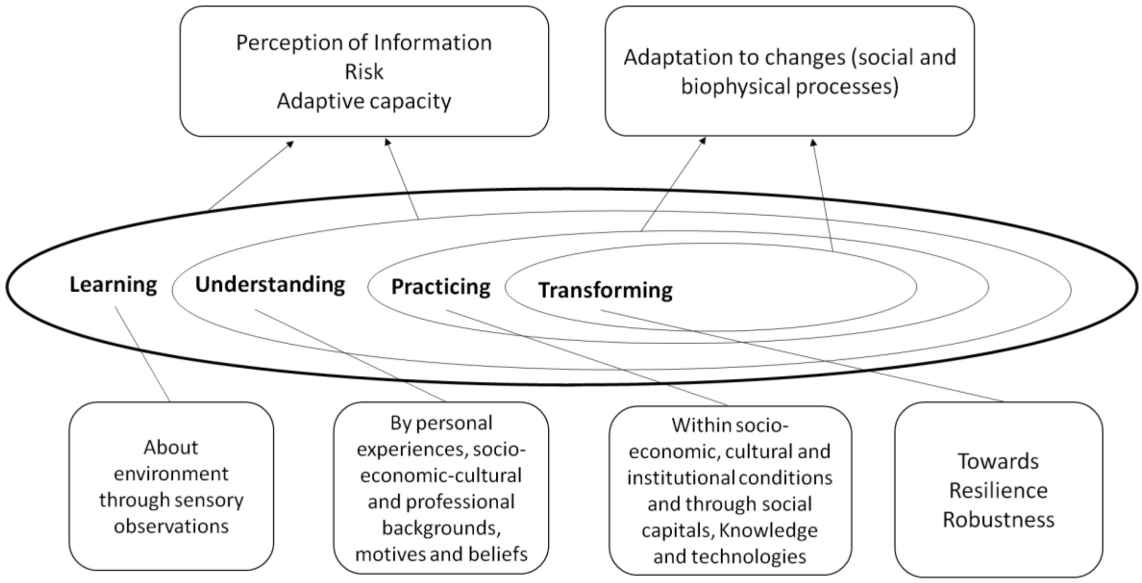

Figure 1: Conceptual framework of the process of perceiving and adapting (based on Nguyen et al. 2016)

Subsequent to these crucial initial steps follows the actual process of adapting to the perceived changes by *practicing* (determined by knowledge, technologies available and influenced by other social capitals such as social networks) and, finally, by *transforming* behavior to assure resilience and robustness. Perceived adaptation options and, ultimately, implemented adaptive response are therefore essentially depending on the two processes involved in perception, the reception of signals (learning), and understanding the signals, which act as 'filters' for the subsequent adaptive reactions. Understanding the processes involved in the perception of signals from the biophysical- and social environment and in their interpretation in terms of evidence for climatic change is therefore key to understand farmers' adaptive responses.

1.3 Research objectives

The objectives of this study are along these lines:

- To identify farmers' perception of changes in the biophysical environment and to determine influencing factors

- To detect interpreted signals and the processes involved in their interpretation

- To comprehend the emergence and meaning of individual understandings of signals and the role personal and social factors play

- To detect patterns of expectation formation significant for making climate change judgments and to identify the role of psychological bias and heuristics

- To derive relevant modeling recommendations for agent-based models that are grounded in empirical observations

1.3.1 Specific research questions

The specific research questions answered in this regard are:

(1) Did farmers perceive changes in typical local weather conditions in recent years? If so, what are their expectations of consequences for farming conditions in the two research regions? And, can demographic, socioeconomic or other variables explain level and direction of perceived changes?

(2) How do individuals engaged in farming conceptualize climate change in their mental models and which role do social representations/socially coined understandings play? Which risk perceptions are derived from observations made in the biophysical and socio-economic environment and how do they influence adaptation knowledge? What is the conceptualization of climate change adaptation among farmers and what are the determinants? Are there feedbacks between perception of changes in weather conditions, expectations of consequences and adaptation knowledge?

(3) How should an appropriate research approach to reveal intrinsic expectation formation be designed? Which expectation formation patterns exist and how can they be distinguished? Can distribution functions be derived and influencing factors for expectation formation be determined?

(4) Which extensions can be recommended for agent-based modeling approaches applied for simulation-based agricultural adaptation assessment with regard to the empirical findings? What are desirable advancements and areas for future research in the given context?

1.3.2 Methodology

Three types of empirical approaches were used to answer the research questions basis to this thesis: questionnaire-based surveys conducted with farmers from the two study areas in Southwest Germany, the Central Swabian Jura and the Kraichgau; questionnaire-based comparative surveys of farmer school students and undergraduate university students enrolled in agriculture-related study programs that had no agricultural background and were before their first semester; and a specifically designed economic lab experiment that was conducted with farmers, farmer school students and university students enrolled in agriculture-related study programs that received several semesters of academic education.

1.3.3 A quick guide through this thesis

This introduction chapter finishes with a background section on global climate change research and the regional-scale research context of the present thesis. Chapter 2 presents empirical findings on farmer perceptions of local changes in weather conditions and their expectations about their consequences for their farming businesses. Chapter 3 introduces empirical studies on social representations, risk perceptions and perceived adaptive capacity of farmers in the research regions. Chapter 4 presents an experimental economics approach to reveal patterns of expectation formation at the level of the individual decision maker. Chapter 5 discusses possible conclusions for agent-based simulation modeling approaches and recommendations for future research.

1.4 Background

1.4.1 An overview of global climate change research

By the time this thesis is being written, it has been 121 years since Svante Arrhenius, a Swedish scientist, in 1896 first articulated the idea that the combustion of fossil fuels could increase the concentration of CO_2 in the earth's atmosphere, stating that this could lead to warmer global surface temperatures (Hulme, 2009). Almost 30 years of intensive scientific research elapsed since the foundation of the Intergovernmental Panel on Climate Change (IPCC) in 1988, in an attempt to discern the significance of natural processes and the proportion of a suspected man-made effect for global climate change, and to subject greenhouse gas emissions to the control of international policy (Hulme, 2017). This man-made effect was suspected to enhance and accelerate the observed increase of average global surface temperatures and other changes in the earth system related to climate variables and to occur since the onset of widespread industrialization in the early- to mid-19th century, based on a correlation between atmospheric CO_2 concentrations and global surface temperatures that was found in time-series data.

The physical phenomenon of climate change - Character and evidence

According to the definition for climate change of the IPCC, [“Climate change refers to a change in the state of the climate that can be identified (e.g., by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, such as modulations of the solar cycles, volcanic eruptions and persistent anthropogenic changes in the composition of the atmosphere or in land use”] (IPCC, 2014a). In contrast, the United Nations Framework Convention on Climate Change (UNFCCC) defines climate change as [“...a change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability observed over comparable time periods.”] (UNFCCC, 1992, p. 3).

One of the cruxes of decision makers trying to make sense out of global climate change is exemplified by the discrepancy between these two definitions: It not only requires a judgment on the question *if* there is an ongoing process of changing climatic conditions, but also on the question for an *anthropogenic cause*. As it is common knowledge, natural climatic changes have always existed. It is also a fact that we live in a world that is the result of these natural changes and that, therefore, also a "natural" adaptation must have taken place that obviously was successful for mankind. This kind of judgment might also have a significant impact for the perception of the nature, severity and urgency of a necessary adaptation to recent man-made global climate change. Along with it comes, for example, a potential anticipation if this recent climate change is going to elapse slow or fast (and thus, comes along with major problems and requirements to adapt *during one’s lifetime*) as well as with the judgment, if its trajectory can at all be influenced or not. Also the latter judgment

– made rationally or not - has an impact on adaptation decisions (O’Neill & Nicholson-Cole, 2009).

The question for its cause

According to the IPCC's latest assessment report published in November 2014 (IPCC, 2014b), human activities caused cumulated CO_2 emissions to the atmosphere in a range of 2040 +- 310 $GtCO_2$ between the years 1750 and 2011. It is expected that around 40% of these emissions remained in the atmosphere, while the rest has been taken up and is stored in plants and soils, and in the ocean. In addition to CO_2 emissions that result from the combustion of fossil fuels, industrial processes, forestry and other land use, a set of other greenhouse gases are released due to human activity and are accounted for in the IPCC assessment reports: Methane (CH_4), Nitrous oxide (N_2O) and fluorinated gases covered under the Kyoto Protocol (F-gases). Those are expected to account for 27.2% of the 100-year global warming potential of current emissions, with the remaining 72.8% being attributed to CO_2 emissions released (based on 2010 emissions and the calculation methodology applied in the IPCC's Fifth Assessment Report) (IPCC, 2014b).

Published in the year 2001, the IPCC's Third Assessment Report states that [“...most of the observed warming over the last 50 years is *likely* to have been due to the increase in GHG concentrations”] (quoted in IPCC, 2007, p. 37), with the qualitative level of confidence expressed as "likely" being associated with a more than 66% probability that the assessment is true, according to the IPCC's uncertainty communication scheme. The IPCC's Fourth Assessment Report (published in 2007) stated that it is ["...*likely* that there has been significant anthropogenic warming over the past 50 years averaged over each continent (except Antarctica)"] and that ["Most of the observed increase in global average temperatures since the mid-20th century is *very likely* due to the observed increase in anthropogenic Greenhouse gas (GHG) concentrations.] (IPCC, 2007, p. 39). The judgment of "likely", again, being associated with a more than 66% probability and "very likely" with a more than 90% probability for the assessment to be true, according to the IPCC's uncertainty communication scheme (IPCC, 2007).

Already seven years later, in the IPCC's Fifth Assessment Report (AR5), the likelihood of anthropogenic drivers to be the dominant cause for the observed warming of the global climate system that has been observed since the mid-20th century is assessed to be extremely likely, referring to a probability of 95-100% (IPCC, 2014b), while the existence of a global warming trend is termed "unequivocal" (IPCC, 2014b, p. 2).

In addition to the question for the cause of an expected ongoing global climate change, the necessary distinction between "normal" climatic variations that would exist even under a stable climate and variations that reflect a long-term changing trend, proved to be a major challenge for scientists over these past decades. While scientists usually use statistics to identify and communicate probabilities, laypeople use a mixture of scientific information, interpretations of experiences gathered from their bio-physical environment, information usually in the form of visual images and simplified messages conveyed by the media and other socially constructed knowledge that is present in their social environment to make sense of the elusive and abstract concept of global climate change (Hansen et al., 2004; Nicholson-Cole, 2005; O'Neill & Nicholson-Cole, 2009; Weber, 2016).

Understanding these factors and their interplay as well as its significance for farm-level adaptation decisions is a major challenge for the assessment of farm level adaptation response (Haden, Niles, Lubell, Perlman, & Jackson, 2012), and has therefore been addressed in the DFG-FOR 1695 sub-project P6 - 'Human-environment interactions'.

1.4.2 Research context

Pathways of climate change into farmers' perceptual systems

Signals of climatic changes convey into farmers' perceptual system in a number of ways: Average temperatures at every season of the year have been observed to frequently reach levels above the ones of previous decades in south-western Germany (Wulfmeyer & Henning-Müller, 2006) and average temperatures as well as frequencies of extreme events such as prolonged heat- and drought periods increases are projected to continue to rise in central Europe (Olesen & Bindi, 2002; Reidsma et al., 2010). In consequence, farmers experience signals that are related to their production activities and usually affect their income: Changed temperatures and precipitation patterns affect growth conditions of field crops, the incidence of weeds, pests and plant diseases and the productivity of animal production systems. Increased CO_2 concentrations are expected to interfere with the resource-use efficiency of plants with regard to radiation, water and nitrogen processing, resulting in - on average - higher yields in most parts of central Europe and for the majority of plants considered, according to Olesen & Bindi (2002).

At the same time negative effects of elevated CO_2 concentrations on yield quality have been described, especially for protein contents in wheat (Högy & Fangmeier, 2008). Climatic changes have been projected to interfere with the timing of field work, yield levels and the relative preferability of cultivars in the research regions (P. Parker, Ingwersen, Högy, Priesack, & Aurbacher, 2016), with effects also for farm-level labor organization and machinery use. The long-term net-effects of climatic changes for crop yields however will likely depend on the combined effects of a changed composition of the atmosphere and the trajectory the climatic changes will take (Olesen & Bindi, 2002) as well as on technological progress, e.g. in terms of crop genetics available (Parker, Ingwersen, Högy, Priesack, & Aurbacher., 2016). Apart from that, farm income opportunities will be influenced by outcomes of the socioeconomic production environment, such as input- and output price developments and agricultural policy outcomes (Troost et al., 2012), which themselves will likely be influenced by climate change effects and thus represent socioeconomic pathways for climate change (Adams, Fleming, Chang, McCarl, & Rosenzweig, 1995; Parry, Rosenzweig, Iglesias, Livermore, & Fischer, 2004).

Research needs at the regional scale

The regional scale has been found to be the relevant scale for decision makers' responses to the perceived effects of climate change, as well for those who directly depend on climate change outcomes (as, for instance, farmers) as well as for policy makers and institutions (Grothmann & Patt, 2005; Haden et al., 2012; Lorenzoni & Pidgeon, 2006; Weber, 2016). To assess climate change response in the agricultural sector and its socioeconomic, micro-economic, and, in addition, potential consequences for agricultural production levels and ecosystem services at the regional scale, the DFG - research projects PAK 346 and FOR 1695 have been implemented. Two regions with differing climatic conditions and the respective adapted farming systems, the Kraichgau and the Central Swabian Jura have been selected to serve as research areas and as modeling regions.

Assessing the effects of agricultural adaptation at the regional scale

To assess the combined effects of biophysical and socioeconomic pathways as well as the consequences of farm decision makers' response at the regional scale, an integrated land system model system (ILMS) is developed within the DFG - FOR 1695 research project. It integrates an atmosphere-land surface-crop model (ALCM1) that delivers simulated weather data at a resolution of 1 km with a coupled bio-economic model system (BEMS), that consists of a plant-growth model (EXPERT-N) to simulate soil, water and nutrition effects on plant growth, a bio-economic model of farmer behavior capable of simulating farm-level activities at fine time resolution (FarmActor), and a recursive-dynamic agent-based farm-level programming model (MPMAS) for the analysis of microeconomic and socioeconomic effects (Warrach-Sagi et al., 2016).

Agent based socioeconomic modeling with MPMAS

D. C. Parker, Manson, Janssen, Hoffmann, & Deadman (2003) define multi-agent system models of land-use/cover change (MAS[3]/LUCC models) as class of models that typically couple a cellular model component that represents a certain landscape, with an agent component that represents human decision-making. Both components are intertwined via formulated interdependencies and feedbacks between the modeled agents and their environment, and between the agents themselves. For the case of multi-agent systems applied to agricultural land use/land cover change (MAS/LUCC) the modeled factors typically comprise of weather, water run-off, soil quality, agricultural (and other) land-use, factor endowment of the virtual farms, (exchange of) property rights, and agent networks for communication and collective decisions (Berger & Troost 2014).

One of the features of future climatic changes and the subsequent farm level adaptive response at the regional scale is, that effects for farm households, agricultural structures and ecosystem services are expected to be highly location specific. Berger & Troost (2014) - among others -point out three components MAS should have to constitute a useful tool for simulation-based agricultural adaptation and land use assessment, and to be able to inform

[3] In this thesis, the terms ABM and MAS are used interchangeably.

more targeted policy interventions in terms of evaluating consequences of adaptation measures on GHG exhaust, as well as other feedbacks of reactions of the agricultural sector into the biophysical environment.

These required properties are:

1. Depiction of technical and financial constraints of the modeled farm businesses at sufficient detail as well as a solid micro-economic footing.

2. Modeling of farmer decision making processes including expectation formation, learning and risk-coping behavior for an improved assessment of innovation diffusion and policy implications.

3. Accounting for exchange of information and other peer interactions relevant for technology use decisions, such as joint use of machinery and other facilities including related processes such as "collective action" and "critical mass".

(Berger & Troost, 2014)

The modeling recommendations developed in the final chapter of this thesis address these requirements and derive hints from empirical findings to improve these features.

2 Farmers' Perception of Changes in Local Weather Conditions - Empirical Survey Insights

The following chapter explores farmers' awareness of changes in typical weather conditions in the two research regions Kraichgau and Swabian Jura. The chapter is based on a contribution to the "Schriften der Gesellschaft für Wirtschafts- und Sozialwissenschaften des Landbaus e.V.", that was published under the title "German Farmers' Perception of Climate Change Effects and Determinants Influencing Their Climate Awareness" (Jänecke, Eisele, Reinmuth, Steinbach, & Aurbacher, 2016). It consists of results from a mail survey conducted in the two research regions in the year 2013.

2.1 Introduction

Climate change is a global phenomenon. It naturally affects weather conditions on regional scale, since they are a spatial representation of the global situation. A potential increment of weather variability will influence agricultural activities and accordingly the productivity of agricultural ecosystems. This applies as well to our study sites, which are located in Southwest Germany in the federal state of Baden-Wuerttemberg and approximately cover the natural areas Central Swabian Jura and Kraichgau. A general definition of the word climate change is given by the Intergovernmental Panel on Climate Change (IPCC). The organization defines the term as *"[...] a change in the state of the climate that can be identified [...] by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer"* (IPCC, 2013), whereby climate describes the average weather, respectively the statistical description of the means of relevant quantities (e.g. temperature and precipitation) over a period of time (IPCC, 2013). In conclusion, variations in climate manifest in changes in the relevant meteorological variables.

At a regional scale, the meteorological time series data gathered and evaluated by the German Meteorological Service (DWD) support the existence of ongoing climate change for the federal state of Baden-Wuerttemberg. Since the beginning of the 20th century (period 1914-2013), the data show an increasing trend of annual mean temperature, especially from the 1980s onwards (cf. Figure 2). In 2013 a mean value of 8.6 °C was observed. Compared to the climate normal period (1961-1990)[4], this value represents a temperature deviation of +0.5 °C (DEUTSCHER WETTERDIENST, 2015b). In addition to mean temperature changes, the effects of global climate change are also reflected in variations of the frequency of

[4] The World Meteorological Organization (WMO) has set the current climate normal period from 1st January 1961 to 31th December 1990 (30-year period) in order to determine the statistical parameters of different climatological variables with satisfactory accuracy (WORLD METEOROLOGICAL ORGANIZATION, 2015).

extreme weather events at the regional scale. While the number of ice days[5] (+1.6 days) and frost days (+5.0 days) only slightly increased between the period 1961-1990 and the year 2013, the quantity of summer days rose by 41.3 % (+12.8 days) (DEUTSCHER WETTERDIENST, 2015b). The frequency of observed days with temperatures > 30 °C (+12.8 days) and days with summer hailstorm events (+1.8 days) even doubled in the period considered (DEUTSCHER WETTERDIENST, 2015b).

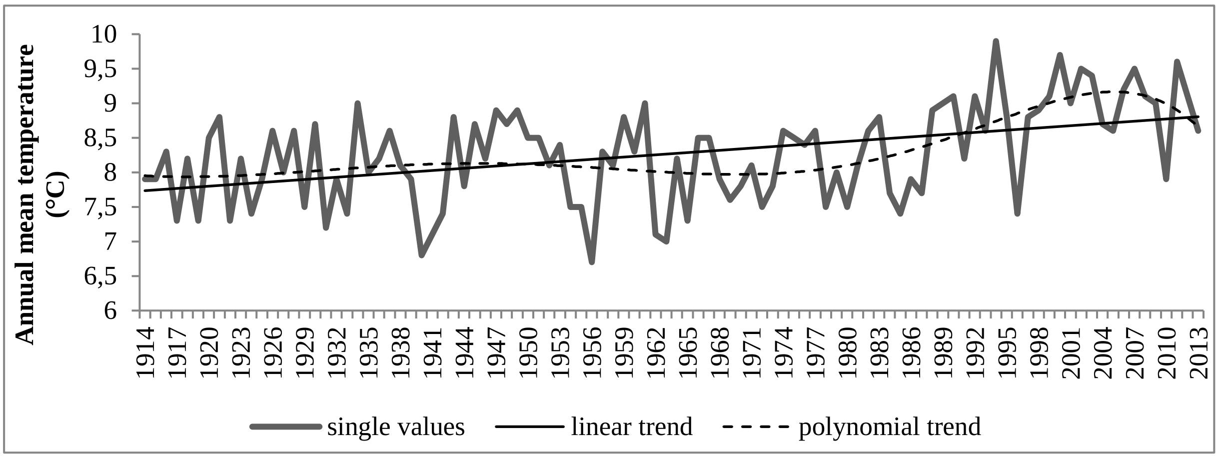

Figure 2: Annual mean temperature in Baden-Wuerttemberg from 1914 to 2013. Source: Main author's illustration with German Meteorological Service data (DEUTSCHER WETTERDIENST, 2015a)

The recent climate change trend will most likely continue in the future (WAGNER, 2013). In order to assess the consequences associated with changing climate conditions, the Ministry of the Environment, Climate Protection and the Energy Sector Baden-Wuerttemberg commissioned a study on potential climate development. The evaluation of different regional climate projections conducted in the study suggests an additional increment in annual mean temperature of +1.1 °C for the period of 2021-2050 (WAGNER, 2013). This is projected to be accompanied by a decreasing frequency of frost days (-19.1 days) and ice days (-8.9 days) in particular, as well as an increasing occurrence of heat days (+2.7 days) and summer days (+10.1 days) (WAGNER, 2013). Besides these variations in temperature, the regional climate projections also outline changes in precipitation (e.g. higher precipitation quantities for the hydrologic winter half year[6]) and an increment in extreme weather

[5] Ice days are defined as days with a temperature maximum < 0 °C, frost days have a temperature minimum < 0 °C, heat days have a maximum in temperature ≥ 30 °C and summer days have a temperature maximum of at least 25 °C (WAGNER, 2013).

[6] Hydrological winter half year covers precipitation quantity for the months November-April in mm and hydrological summer half year includes precipitation quantity for the months May-October in mm (WAGNER, 2013).

events (e.g. a prolongation of drought periods) (WAGNER, 2013). Scientific research considers the changes of global climate conditions predominantly as negative, since they connote an important risk for agricultural ecosystems and food supply.

2.2 Farmers' perception of local weather conditions

Nevertheless, evaluation of the predicted impacts requires a differentiated consideration at the regional scale. Depending on the location of farm businesses, climate change will affect agricultural practices in various directions. For that reason, understanding farmers' perception of changes in typical weather conditions is important, especially as it is the basic precondition to guide future strategies for adapting agricultural activities to climate change at the farm level. Hence, the major objective of this research paper is to investigate farmers' perception of changing weather conditions and potential effects for their businesses as well as to ascertain determinants influencing their attitude toward climate change. For this purpose, the paper is structured as follows: Section 2.3 briefly presents the econometric model and data used for analyses. Section 2.4 highlights the main estimation results. Finally, the research paper ends with a discussion of the outcomes and conclusions in section 2.5.

2.3 Material and method

Data

The data used in our analyses are taken from a study on perceptions and attitudes toward climate change. In May 2013, questionnaires were mailed to 739 farm managers in the study sites. The survey contained 39 open-ended and closed-ended questions (BRYMAN, 2008), subdivided into nine major categories: basic farm characteristics, experience in farming, use of information sources for decision making and information on decision finding. Furthermore, questions on perception of climate change effects, adaptation measures, information on risk attitudes, income expectations and demographic attributes were posed.

Questions related to the perception of climate change effects were set up as series of statements on changes in local weather conditions[7]. The question that preceded the weather statements was: "If you look at the time you spent working at your farm, how strongly would you agree with the following statements with respect to how they apply to your location?" With the response items: 1) "The weather has changed over the years," 2) "With respect to weather there are more and more extreme years," 3) "The weather is changing to my farm's disadvantage" and 4) "The weather is changing, but it's neither to my farm's

[7] The authors' experiences from previous surveys indicate difficulties for farmers to understand and make statements if the word climate is used, most likely because it is a rather abstract scientific concept. Instead, a synonymous understanding and use of the term "weather" (meaning weather conditions typical for a certain time of the year) was found to be common among farmers. Due to this fact and the IPCC definition of climate, the authors decided for the application of questions referring to weather conditions in the survey.

advantage nor disadvantage."[8] Respondents were asked to indicate their level of agreement on a seven-point Likert scale that ranged from 1-"completely agree" to 6-"do not agree at all", with an additional response option 7-"not possible to tell".

In total, 173 of the mailed-out questionnaires were returned (82 from Central Swabian Jura and 91 from Kraichgau), resulting in a final response rate of 23.4 %. The representativity of the sample of respondents with regards to the population in the study sites in terms of demographic attributes is difficult to assess due to missing data. With respect to farm characteristics (particularly farm size and share of full-time/part-time managed farm businesses), the sample was not representative compared to agricultural statistics data provided by the State Office of Statistics Baden-Wuerttemberg (STATISTISCHES LANDESAMT BADEN-WÜRTTEMBERG, 2014).

Method and Model Specification

Regression analysis is a multivariate technique used to investigate the relationship between a continuous dependent variable and one or several independent variables (MONTGOMERY ET AL., 2012). For the purpose of our study, this analytic approach is adopted to investigate the influence of various predictors on farmers' perception of climate change. The general empirical specification of the regression models is:

$$y = \beta_0 + \beta_1 region + \beta_2 age + \beta_3 profit + \beta_4 ing\_agr + \beta_5 area\_sum + \beta_6 mgm + u.$$

In this equation the response variable y represents the level of agreement of the farmers with each respective statement. The terms β_1 to β_6 denote the parameters that describe the average change in the response variable per change of one unit in the corresponding predictor, ceteris paribus (MONTGOMERY ET AL., 2012). For ease of interpretation, the scale of the attitude variables was recoded before performing regression analyses so that higher scores are now associated with a higher level of agreement[9]. This scale reflection results in a simplification of the regression coefficients' interpretation in particular with regard to the direction of the effect.

Perception of weather conditions may be driven by various factors. We based the analyses of potential explanatory variables on empirical literature, previous studies and also on available data from the survey. One relevant aspect in terms of climate change perception might be the location of the farm business in one of the study sites, Central Swabian Jura and Kraichgau. The study sites were selected so as to represent different agricultural conditions with specific climate and soil properties. The Central Swabian Jura is a large karst region, characterized by cold and harsh climate with an annual precipitation ranging from 800-1,000 mm. In contrast, the Kraichgau is a fertile hilly region with mild climate, a higher

8 The question and related items were presented in German language in the survey: "Wenn Sie auf die Zeit schauen, in der Sie auf Ihrem Betrieb wirtschaften, wie stark würden Sie folgenden Aussagen für Ihren Standort zustimmen?" Items: 1) "Das Wetter hat sich über die Jahre verändert", 2) "Bezüglich des Wetters gibt es immer mehr extreme Jahre", 3) "Das Wetter verändert sich zum Nachteil meines Betriebes" and 4) "Das Wetter verändert sich zwar, daraus ergeben sich aber weder Vor-, noch Nachteile für meinen Betrieb."

9 New Likert scale used for regression analyses: 1-"do not agree at all", 6-"completely agree". Scale category 7-"not possible to tell" was coded as missing value.

annual mean temperature and moderate precipitation (720-830 mm p. a.). Due to these specific climatic conditions, we hypothesize an effect of the farm business location on farmers' perception of weather conditions. As similar studies find, accumulated knowledge about climate change and its effects, experience in farming as well as success in evaluating weather are associated with a higher age because older farmers have been exposed to past climate conditions for a longer life span (DERESSA ET AL., 2009; MADDISON, 2007). Due to this aspect, we assume an influence of farmers' age on perception of changes in weather conditions and consequences for farm management. Farm income can be used as indicator for wealth (DERESSA ET AL., 2009). Sufficient monetary resources are required for adapting costly agricultural practices or financially challenging investments, for example to hedge against increased climate risks (KNOWLER AND BRADSHAW, 2007), and more wealthy farmers might therefore be less concerned about climate change. Off-farm income represents the importance of farming for the respondent and mirrors the household's dependency on agricultural business (LI ET AL., 2013). Hence, we assume an influence of income on climate change perception and on the awareness of effects for the farm business. In total, two variables represent the farmers' income structure in the analyses: the expected annual farm profit[10] and the share of agricultural income from total household income. The size of a farm is related with more wealth (DERESSA ET AL., 2009) and a greater capacity to mobilize resources with regard to climate adaptation (FRANZEL, 1999). To investigate whether there is a relationship between farm size and the perception of changes in local weather conditions, we included the variable in the regression model as well. Organic farming is associated with increased environmental awareness. At the risk management side, pest control poses a great challenge under changing weather conditions for farm managers who practice organic farming. For that reason, we expect an effect of the production method for the perception of weather conditions and of potential consequences for the farm business.

Table 1 provides a brief description of the predictors included in the analyses. The descriptive statistics of the data collected and the model estimations are performed using the statistical software Stata version 12.0 (STATACORP., 2011).

[10] The question on expected annual farm profit was: "What level of annual operating profit/annual surplus before tax do you expect from your farming operation in a typical year?" with the corresponding question in German language: "Mit welchem Betriebsgewinn/Jahresüberschuss vor Steuern rechnen Sie aus Ihrem landwirtschaftlichen Betrieb in einem typischen Jahr?"

Table 1: List of predictor variables included in the regression models

Label	Description	Measurement	Variable type
region	Region of farm	1-Kraichgau; 0-Central Swabian Jura	Binary
age	Age of respondent (in years)	Numeric value	Continuous
profit	Mean annual farm profit (in 1,000 €)	Numeric value	Continuous
inc_agr	Share of agricultural income from total household income (in %)	Numeric value	Continuous
area_sum	Cultivated agricultural area (in ha)	Numeric value	Continuous
mgm	Production method	1-organic; 0-conventional	Binary

2.4 Empirical results

Descriptive Statistics

Table 2 presents descriptive statistics for the total sample. The results show a balanced distribution of participating farms in terms of their regional allocation. Given that females account for only 2 % of respondents, the farming in both study sites is dominated by males. The farmers' average age is 51 years over all respondents, with an age span that ranges from 24 to 84 years. The mean farm profit of the participating farmers/farm managers amounts to 46,400 € per year, whereas on average 63 % of the total household income is covered by agricultural activities. Farmers cultivate 97 hectares of agricultural area (including arable land, grassland, woodland and special crops), on average. As the majority of farmers manage the business in full-time, this type of farms is over-represented in the sample as compared to data of the State Office of Statistics Baden-Wuerttemberg (STATISTISCHES LANDESAMT BADEN-WÜRTTEMBERG, 2014). With respect to the production method applied, almost all respondents (92 %) practice conventional farming. Data further reveal that sampled farmers have on average 30 years of experience in the agricultural sector, indicating long-time professional agribusiness knowledge of most of the responding farmers.

Table 2: Descriptive statistics of the survey

Characteristics	Respond-ents	Mean	Standard devia-tion
Gender of respondent	170	0.98	---
Practical experience in agriculture (in years)	167	30.22	10.99
Scope of farm business	173	0.61	---
Age of respondent (in years)	169	51.10	10.13
Region of farm	173	0.53	---
Production method	173	0.08	---
Mean annual farm profit (in 1,000 €)	138	46.39	39.97
Share of agricultural income related to total household income (in %)	158	62.54	34.88
Area of agricultural land (in ha)	172	96.46	106.09

Farmers' perception of climate change effects

A change in local weather conditions as a perceivable effect of climate change seems to be sensed by the majority of respondents, as 73 % agree to statement 1 “The weather has changed over the years” and 58 % reject statement 2 “The weather is more or less as it always has been” (cf. Table 3). In particular, 71 % of the farmers perceive an increasing frequency of extreme years (statement 4) and a slight majority (52 %) evaluates weather conditions for them as less predictable (statement 3) (cf. Table 3). Almost three-quarters of the surveyed respondents notice a change in weather, but only 35 % agree to statement 7 “The weather is changing, but it’s neither to my farm’s advantage nor disadvantage” (cf. Table 3). Although the majority of respondents (59 %) do not consider the effects of weather changes positive (statement 5), there is an obvious disagreement among survey participants concerning statement 6 that weather conditions are changing to their farm’s disadvantage, where almost as many farmers agree (42 %) as disagree (41 %) to this aspect (cf. Table 3).

Table 3: Farmers' perception of changes in weather

Statements variables	Sample (% of n=173)		
	Disagree	Agree	"not possible to tell" or no statement
Statement 1: "The weather has changed over the years."	21.97	72.83	5.20
Statement 2: "The weather is more or less as it always has been."	57.80	32.95	9.25
Statement 3: "It gets more and more difficult to predict the weather."	35.26	51.45	13.29
Statement 4: "With respect to weather there are more and more extreme years."	23.12	71.10	5.78
Statement 5: "The weather is changing to my farm's advantage."	58.96	23.70	17.34
Statement 6: "The weather is changing to my farm's disadvantage."	40.46	41.61	17.92
Statement 7: "The weather is changing, but it's neither to my farm's advantage nor disadvantage."	46.24	34.68	19.08

Note: Likert scale ranges 1 to 3 (1-"do not agree at all"; 2-"disagree"; 3-"somewhat disagree") are summarized as "Disagree" and ranges 4 to 6 (4-"somewhat agree"; 5-"agree"; 6-"completely agree") as "Agree".

Determinants influencing farmers' perception of climate change effects

Table 4 depicts the results of the econometric multiple regression models for four of the statements on local weather conditions (statements 1, 4, 6 and 7). Demographic characteristics and other factors (as discussed in Section 2.2) serve as predictors, which hypothetically affect the response variables' level of agreement to the respective statements.

Using the Shapiro-Wilk normality test (SHAPIRO and WILK, 1965; ROYSTON, 1982), the linear model assumption of normally distributed residuals is rejected for the regression models 1 and 2. Based on the central limit theorem, WOOLDRIDGE (2013) concludes that on one hand, the larger the sample size, the closer a distribution is to normality ($n \geq 30$; GHASEMI and ZAHEDIASL, 2012; BACKHAUS ET AL., 2011). On the other hand, the fulfillment of all the further classical linear model assumptions results in an approximate normal distribution. Hence, no problems should appear for the analyses due to the violation of this assumption. Furthermore, the regression models were checked for multicollinearity, using test methods such as variance inflation factor (VIF) and its reciprocal term, the tolerance

(1/VIF) (ACOCK, 2010; WEIBER and MÜHLHAUS, 2010; BACKHAUS ET AL., 2011). Small VIFs[11] with values < 10, tolerance values[12] > 0.1 and low correlations among predictors (values < 0.8) indicate no cause for concern in terms of multicollinearity for all of the models presented here. The number of observations differs between the models from 114 to 133 cases, as result of missing data on either the response variables or the predictors.

Model 1: "The weather has changed over the years."

The first regression model examines farmers' perception of changing weather conditions over the years (cf. Table 4). In Total, 20 % (R^2 of 0.200) of the variance in the agreement scores toward the statement can be explained by the four statistically significant predictors. Regression findings reveal a negative relationship of the variables concerning farmers' age as well as the annual farm profit (for both $p \leq 0.05$) and the perception of climate change effects. Furthermore, study site and the share of income from agricultural activities influence the awareness of changing weather conditions positively at a 1 % error probability level. A statistically significant relationship between the level of agreement to the statement "The weather has changed over the years" and the remaining predictors (production method and farm size) could not be established.

Model 2: "With respect to weather there are more and more extreme years."

Regression model 2 focuses on the identification of factors influencing the level of agreement to the issue of more frequent occurrence of years with extreme weather conditions. The moderate goodness of fit (R^2 of 0.164) implies that the independent variables explain approximately 16 % of the variance in the response variable. Table 4 summarizes the results of the regression analysis. In total, four statistically significant predictors are found to affect the agreement scores for the statement "With respect to weather there are more and more extreme years." The location of the farm ($p \leq 0.10$), the share of agricultural income ($p \leq 0.05$) and the method of production ($p \leq 0.05$) are positively associated with the perception of an increasing occurrence of extreme years. The annual farm profit shows as well an effect on the respondents' agreement level to this statement, but it is negatively related (significance is at a 1 % level). A statistically significant influence of the remaining predictors, which capture farmers' age and farm size, has to be rejected, based on our model.

Model 3: "The weather is changing to my farm's disadvantage."

The third regression model establishes the respondents' degree of agreement to the statement of emerging disadvantages for the farm business due to changes in weather conditions (cf. Table 4). In total, two variables explain about 12 % of the variance in the perception of

[11] FREUND ET AL. (2006) suggest that a VIF exceeding a value of 10 is an indicator of the existence of multicollinearity. This cut-off value is also proposed by ACOCK (2010). WEIBER and MÜHLHAUS (2010) recommand a more conservative cut-off value of > 3. In these multiple linear regression analyses VIF for all predictor variables were < 10 (1.03-2.74). Naturally, only the variables *age* and *sq_age* in the multiple regression model 1 and the variables *profit* and *sq_profit* in the regression models 1, 2 and 3 showed magnitudes > 10 because one variable is the square term of the other.

[12] Conversely to the cut-off value of VIF < 10, ACOCK (2010) states that a tolerance value > 0.1 causes no problems of multicollinearity.

negative consequences of changes in weather conditions (R^2 of 0.119). A positive effect, at a 5 % level of significance, is found for the location of the farm. The results in Table 4 further show a significant negative influence of farmers' age ($p \leq 0.05$) on level of agreement to the statement "The weather is changing to my farm's disadvantage." For the remaining predictor variables, which cover share of agricultural income, annual farm profit, production method and farm size, the analysis shows no statistically significant effects.

Model 4: "The weather changes, but it's neither to my farm's advantage nor disadvantage."

The fourth regression model examines the agreement scores of farmers to the statement that neither advantages nor disadvantages arise for their farms due to changes in weather conditions. Overall, approximately 18 % (R^2 of 0.180) of the variation in the level of agreement to the response variable can be explained by using the set of predictors. The model findings (cf. Table 4) indicate that farmers' age ($p \leq 0.01$) and farm size ($p \leq 0.05$) are positively correlated with the response variable reflecting the level of agreement to this statement. A statistically significant influence on the degree of agreement to the issue is also found for the region and the agricultural production method. These variables are negatively related with the response variable, both at a 5 % error probability level. The remaining predictors concerning income (share of agricultural income and annual farm profit) have no statistically significant effect on the awareness of either positive or negative consequences that result from changes in weather.

Table 4: Results of the multiple linear regression models on climate perception, extreme events and consequences for farm management

	Model 1	Model 2	Model 3	Model 4
Dependent Variables	“The weather has changed over the years.”	“With respect to weather there are more and more extreme years.”	“The weather is changing to my farm’s disadvantage.	“The weather changes, but it’s neither to my farm’s advantage nor disadvantage.”
region(a)	0.685 ***	0.427 *	0.607 **	-0.773 **
age	-0.156 **	-0.0188	-0.0285 **	0.0463 ***
sq_age	0.00139 *	------	------	------
profit	-0.0266 **	-0.0288 ***	-0.0155	------
sq_profit	0.000167 ***	0.000197 ***	0.000111	------
h_profit	------	------	------	-0.000000257
inc_agr	0.0151 ***	0.0112 **	0.000316	-0.00766
area_sum	-0.00390	-0.00469	-0.00342	0.00758 **
mgm(b)	0.606	0.922 **	0.00547	-0.967 **
_cons	8.100 ****	5.273 ****	5.162 ****	1.184
N	130	133	117	114
R^2	0.200 ****	0.164 ***	0.119 **	0.180 ***

Note: (a) 1-Kraichgau, 0-Central Swabian Jura; (b) 1-organic farming, 0-conventional farming; the variables *sq_age*, *sq_profit* and *h_profit* were used to model a nonlinear relationship; *sq_age* and *sq_profit* refer to the square terms of the variables age and profit; *h_profit* refers to the hyperbolic term (cube) of the variable profit; scaling of response variables: 1-“do not agree at all” to 6-“completely agree”; level of significance: * $p \leq 0.10$, ** $p \leq 0.05$, *** $p \leq 0.01$, **** $p \leq 0.001$

2.5 Discussion of results and conclusions

In this research paper, a sample of 173 German farmers from the regions Central Swabian Jura and Kraichgau has been analyzed with regards to their perception of climate change effects, in order to identify the influence of demographic attributes, aspects of farm household as well as farm characteristics. For investigating the determinants on their attitude to certain weather statements, four multiple linear regression analyses were employed. The general finding that farmers perceive changes in climate is in line with outcomes of several other studies, which were conducted in Africa (NDAMBIRI ET AL., 2013; OKONYA ET AL., 2013), North America (VAN HADEN ET AL., 2012; ARBUCKLE ET AL., 2013) and China (LI ET AL., 2013).

Based on our results, the location of the farm in either one of our two research regions influences the perception of climate change effects. Respondents of the Kraichgau show a more distinct perception of changes in weather conditions and increasing frequency of extreme years, as compared to their colleagues from the Central Swabian Jura. They also state to be aware of a generally negative trend of consequences occurring for their farms due to a change in weather conditions. The perception of changes in weather conditions and the pessimistic attitudes of Kraichgau farmers toward climate change effects might be attributed to the focus of their farm businesses, which typically is on the cultivation of crops. About 83 % of the agricultural land in the region is used for the production of cash crops and also special crops. The effects of climate change might be more damaging for Kraichgau farmers because the region is one of the warmest in Germany, and changes in weather conditions, for instance an increase in temperature, might negatively affect the production and could quickly lead to crop failures. Furthermore, it is conceivable that global climate change showed a stronger manifestation in the region Kraichgau in the past due to its climatic characteristics (higher annual mean temperature and moderate precipitation) and therefore the farmers have a more distinct awareness of changes in weather.

The results of our regression analyses imply a negative correlation between level of agreement to the statements of changing weather conditions as well as the more frequent occurrence of years with extreme weather events and the age of respondents.[13] Interestingly, these outcomes contradict the conclusions of other surveys, where the perception of changes in climate and the age of the respondent are positively related (NDAMBIRI ET AL., 2013; OFUOKU, 2011; OKONYA ET AL., 2013). As possible explanation for this finding, it is conceivable that older farmers might attribute less importance to years with extreme weather events when assessing climate conditions due to their longer reference period and hence might consider these years (e.g. the drought of the year 2003) not as a trend in climate conditions. The older farmers are conceivably more conservative and traditional in terms of their attitude toward farming and might explain the extreme weather events with natural

[13] The “Peak Age” can be calculated using a modification of the formula of WEBER (2008: 186): $1 * -\beta_{age} / (2 * \beta_{sq\_age})$. For the model 1, the following formula applies: 1 * -(-0.156) / (2 * 0.00139) = 56.115. The result indicates an increase of the level of agreement from the age of 56.1 years due to the positive algebraic sign of the regression coefficient of the variable *sq_age*.

climate variability (EGGERS ET AL., 2015; MCRAE-WILLIAMS, 2009). In contrary, younger farmers might be more concerned about the long-term climatic conditions at their location and therefore more sensible when assessing weather conditions because they will be managing their farm businesses until further in the future. Another aspect could be information collection patterns: younger farmers are often more familiar with the use of new information technologies than older ones (STRICKER ET AL., 2001). Hence, they might more easily gather information to follow the scientific discussion on climate change.

OKONYA ET AL. (2013) unveil that farmers with off-farm income sources perceive climate change more strongly. This statement is contradicted by the findings of our study, as the farmers' awareness of changes in weather conditions increased with the share of agricultural income from total household income. A possible explanation might be that no additional income source besides farming increases the dependency of farmers on agriculture (LI ET AL., 2013). Furthermore, off-farm activities might compete with the production on farm, what might result in a shifting focus on non-agricultural activities and an altered perception of climate change (NDAMBIRI ET AL., 2013). The authors SEMENZA ET AL. (2008) establish with their survey of U.S. American households that high-income groups are more likely to be aware of climate change than low-income groups. In contrast, NDAMBIRI ET AL. (2013) find a negative (albeit not significant) relationship between farm income and perception of climate change. Our results support the finding of NDAMBIRI ET AL. (2013), as we find a decreasing perception of changes in climate with increasing farm profit[14]. This reversal of the impact for the case of respondents might be driven by the fact that farmers typically share common characteristics, such as dependence of production and farm profits from the variability of nature. Thereby, dependence and sensitivity might be less for more wealthy farmers, e.g. due to a greater range of opportunities to buffer climate related risks, for instance by technological means (e.g. the use of more powerful machines) or via financial means (e.g. insurances).

GRAMIG ET AL. (2013) establish in their study a negative relationship between farm size and the belief that climate change will not affect the farm management. Conversely to that statement, the results of our analysis suggest that respondents owning enterprises with large area tend to assess consequences of climate change effects as neither positive nor negative, compared to farmers who run farms of smaller scales. Hence, a higher level of agreement that no effects on how farmers operate their farms emerge due to changes in weather is associated with increasing farm size. Maybe, the direct dependence of farmers on climate raises especially the awareness of the less profitable farm owners with regard to climate change; an effect which is not visible in the general public. The finding might also be elucidated by the relationship of farm size and wealth. Because farmers owning enterprises

[14] The "Peak Profit" can also be calculated using a modification of the formula of WEBER (2008: 186). Regarding the positive algebraic sign of the regression coefficient of the variable *sq_profit* in the models 1 and 2, the level of agreement increases with the value of 79,640 € (Model 1) and the value of 73,096 € (Model 2).

with large area commonly generate more profit, they have as well greater monetary resources to implement appropriate adaptation strategies for adjusting their farm activities to reduce climate risks and are therefore less concerned about climate change effects.

Farmers who follow organic production schemes show a more distinct level of agreement to the statement "With respect to weather there are more and more extreme years" than their colleagues who manage their farms conventionally. The positive correlation between the corresponding statement and organic production supports our hypothesis that the production method farmers apply influences the degree of agreement to the statement of more frequent occurrence of extreme years. In addition to this outcome, respondents who practiced organic farming more often believed that changes in climate will affect their farm activities, contrary to farmers practicing conventional methods. The explanation for the finding might be that farmers with organic production are more vulnerable for damages referring to changing weather conditions because they depend on the use of non-chemical-synthetic plant protection products for pest control, for example.

In general, the moderate coefficients of determination (R^2) and model findings suggest that besides the analyzed determinates other relevant factors exist, which explain a large share of the variation in the perception of changing weather conditions. Some studies reveal a relation between gender and the perception of climate change (FALAKI ET AL., 2013; NDAMBIRI ET AL., 2013). However, due to the fact that there are only four female respondents in the sample of 173 survey participants, the analysis of the gender effect on awareness of changes in climate is not possible. Initially, the level of education and the farms' main production activities were expected to have an effect on the magnitude of agreement to the perception of climate change effects. Nevertheless, no significant relationship could be found in the analyses and the related variables have been removed from the models. The finding is particularly surprising for education level because several studies reveal a higher probability of more educated farmers to be aware of changes in climate than of less educated ones (OFUOKU, 2011; NDAMBIRI ET AL., 2013). Hence, these preliminary findings indicate that a need for additional research on this topic remains in order to investigate and to understand the primary drivers of climate change perception among farmers in high-income countries, e.g. in Germany. Due to the discovery that the overall level of awareness of changing weather conditions among farmers of the two study sites Central Swabian Jura and Kraichgau is high, future research on regional scale should focus and explore the potential of appropriate adaptation strategies that enable farm business managers to reduce potential negative effects of ongoing climate change for their businesses.

The sample is not representative for the population of agricultural businesses in the regions Central Swabian Jura and Kraichgau due to the composition of the survey participants in terms of farm size and farm business structure. Particularly, the study represents the weather perception of successfully operating farmers with large farm businesses mainly managed in full-time. We assume that these farmers will quite likely continue farming in the nearer future. An important aspect with respect to the research topic is the low availability of studies investigating the climate change perception of farmers in Europe (EGGERS ET AL., 2015; BARNES and TOMA, 2012; KARRER, 2012). In regard of that the findings of this study contribute to the understanding of perceptions of climate change and expectations toward it’s effects as well as it serves as basis for further research, even though they cannot be generalized.

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3 Social Representations of Climate Change, Farm-Level Risk Perception and Perceived Adaptive Capacity

This chapter investigates how individual conceptualizations of climate change evolve and how they are influenced by own experiences and interactions within social groups. For this purpose, social representations of climate change present in the social group of (young) farmers are compared to the ones present in pre-first semester undergraduate university students enrolled in agriculture-related study programs without farming background and practical experience in farming, based on surveys conducted from 2013 to 2017. As further task, perceptions of farm-level risks among farmers are explored and compared within two empirical surveys conducted in the project's research regions in the years 2010 and 2013. The latter survey also measured perceived adaptive capacity in terms of knowledge about farm-level measures that were understood as suitable reactions to the challenges in agriculture caused by climatic changes. By using this data, the following chapter also elaborates the conceptualizations of farm-level adaptation present in farmers, as well as the relationship between perceived risks, personal- and farm characteristics, and the stated adaptation knowledge.

3.1 Introduction

A multitude of risks are simultaneously present at the farm level, and climate- and weather variability are only two of the manifold causes that threaten farm profit and other factors crucial for a farm manager's utility, such as health and a satisfying family- and social life. Therefore, it can be expected that the perceived urge and importance of certain risks are important influencing factors for adaptation decisions (Weber, 1997). The special characteristics of climate change however have consequences for perceptions of the concept and the social construction of knowledge about it, and this influences judgments on risks involved and about the appropriate measures to take (Baer & Risbey, 2009; Moloney et al., 2014; Weber, 2010). For understanding adaptation choices, it is therefore crucial to understand how cognitions of climate change develop (Nguyen et al., 2016) and, especially, how people construct and represent climate change within their mental models, among other reasons for the fact that scientific findings provide hints that certain types of visual and mental imagery might even induce counter-productive reactions (Moloney et al., 2014; Nicholson-Cole, 2005).

Adaptation choices themselves come along with a high degree of uncertainty about their efficiency and effects in the short- as well as in the long run. The perceived urge and magnitude of considered reactions therefore likely depends on (i) the reception, experienced outcomes of-, and socially influenced interpretations of signals interpreted as effects of ongoing climate change, (ii) the perceived vulnerability of production activities and the farm business as a whole, and (iii) the perceived adaptation efficacy, which is a combination of knowledge of adaptation options and subjective judgments about their effect for accomplishing a desired level of performance (Broomell, Budescu, & Por, 2015). Therefore, the level of knowledge about adaptation options likely reflects as well how much effort an individual has spent thinking about these issues, i.e. can be taken as a proxy for the perceived challenges caused by climate change and their perceived significance for that person.

3.2 Motivation

Assuming the aforementioned interrelationships, a combined assessment of social representations of climate change commonly employed by farmers, of farm-level risk perceptions and their dynamics, as well as of farmers' knowledge of adaptation measures is conducted to draw conclusions on interpreted signals for climate change, perceived adaptation needs, the influence of social interactions as well as of personal factors, and on the presence of counterintuitive and in the long run likely counterproductive coping strategies, such as wishful thinking, ignorance or fatalism.

To answer the question if farmers and scientists share the same understanding of adaptation to climate change and, especially, which features of adaptation farmers favor, elicited knowledge about adaptation options will further be interpreted in terms of mental models (Bostrom, Morgan, Fischhoff, & Read, 1994; Hansen et al., 2004) about adaptation. To do so, the nature of the stated measures is analyzed with regard to conclusions to be drawn about the mental model the respondents employed about the effects of climate change on their farm businesses and about suitable responses and their effects. Further hints on vulnerability and perceived efficacy are derived from the number of measures mentioned, statements of opinions or wishes and as well from non-responses. The findings allow for conclusions on which signals are interpreted in this context and which pathways they take into an individual's cognitive system, their interpretation in terms of farm-level risks and about their significance for the conceptualization of adaptive response and perceived adaptive capacity.

3.3 Methods

3.3.1 Social representations theory

The process of social representation is triggered when an appearing event challenges a group's identity and when communicating the novel disrupts existing social rules. The new event or phenomenon is coped with by first anchoring it to familiar terms, which means naming, understanding and interpreting it according to these existing terms and representations (Wagner et al., 1999). Subsequently, further discourse and elaboration generates a new social representation that is shared by the members of the social group and that then might even reinforce the group's social identity. This second part of the process is referred to as objectification. It means that a social construct in the form of an icon or a metaphor is created, that figuratively stands for the new phenomenon or idea, and is shared and understood by the members of the social group and enables them to communicate about the phenomenon (Wagner et al., 1999). In this sense, social representations constitute a system of values, ideas and practices that are shaped and coordinated by interactions between individuals, groups, institutions and the media (Moloney et al., 2014).

Use of word association techniques and open questions

Besides other methods of empirical research (see, for instance Wagner et al., 1999) statistical analysis of word associations has been used to generate empirical insights in the context of the social representations theory. Contrary to other methods, applying word association techniques and open-ended questions allows to explore individual understandings and associations connected with certain concepts, as the question design gives space for free answering. It can be expected that due to that, more spontaneous and intuitive responses are triggered, as compared to - for instance - those acquired with focus groups or Likert scales, and that responses are less influenced by considerations of political correctness (Marková, 1996; Moloney et al., 2014) and probably strategic answering as well. A similar advantage can be assumed with regard to the type of researcher-induced biases that come along with item-selection, combination, order, wording and scale setting. Employing word associations elicitation techniques and the social representations theoretical framework is therefore intended to measure value laden knowledge that has accumulated in groups and societies (Marková, 2017) through interactions of the members of social groups with each other and with the environment. In this sense, applying the technique allows to explore how people think (Marková, 2017).

3.3.2 Data collection and analysis

Moloney et al. (2014) used a word association elicitation approach to research differences in the social representations of climate change within different social groups in Australia. They applied an open-ended question to elicit spontaneous associations with the term "climate change" and subsequently categorized them under the most frequently occurring association after homogenizing the statements, i.e. cleaning the data for semantically similar words, miss-spellings, plurals, singulars, etc. A similar approach was selected for this study and will be explained in the following.

Research problem 1: Social representations of Climate Change

During workshops conducted with young farming practitioners from the research regions and their close proximity[15] (two were conducted at farmer schools in 2013 and one at the University of Hohenheim in 2015), participants were asked to state "What comes first to your mind when you think about climate change? Please indicate in note form."[16] Application of this word association task was then repeated during workshops with students that had registered in agriculture-related undergraduate study programs at the University of Hohenheim but were before the start of their first semester. In addition to that, those students that had an agricultural family background were excluded.

Research problem 2: Perception of significant farm-level risks and perceived adaptation options

A similar survey approach was applied to explore perceptions of farm-level risks and conceptualizations of farm-level adaptation to climate change. The questionnaire-based mail survey conducted among farmers located in the two research regions in 2013 contained an open-ended question that read: "What are, according to your opinion, the major risks in your farm business? Please list the most important risk first or number the risks according to their significance."[17] Outcomes of this survey are in the following compared to answers given to a similar question[18] employed in questionnaire-based personal interviews with 53 farm leaders from the two research regions, in a survey conducted by the author and a second enumerator in 2010.

Research problem 3: Mental models about adaptation to climate change and perceived adaptation efficacy

Mailed-out questionnaires of the 2013 survey also featured a question designed to elicit farmers' knowledge about farm-level adaptation measures. It was implemented as "In your region: What are, according to your opinion, the best options for a farming business to prepare already now for potential effects of climate change? Please explain shortly or note a few keywords."[19] The actuality involved with this formulation had been introduced to motivate answers that referred to realistically considered - or even already implemented -

15 The farmer schools were located in the cities of Aalen, Bruchsal and Sigmaringen.

16 See Appendix section B.1.1 for the original formulation of the question.

17 See Appendix section B2.1 for the original formulation of the question.

18 The question was formulated as: "What is the most significant risk in farming for you?". See Appendix section B.2.1 for the original formulation of the question.

19 See Appendix section B3.1 for the original formulation of the question.

changes, instead of hypothetical responses, an approach that would also give hints for farmers current mental models about the impacts of climatic changes and about the related perceived adaptive capacity, both implicitly contained in the answers given. Also, conclusions on currently perceived vulnerability are enabled in this way, as the number of adaptation options recalled likely reflects the effort a respondent spent thinking about how to cope with climate change effects, which in turn likely is related to the perceived severity and urge to react.

Analysis

A total of 123 undergraduate students without personal experience in farming (defined as neither internship, family background or formal education in agriculture) were evaluated as a subset of 390 pre-first semester University students who answered the word association question in total, and a total of 52 farmer school students did so. On average, 2.26 statements of word associations were given by the freshman university students and 1.14 by the young farmers. From 739 of sent-out questionnaires in the 2013 survey, a share of 173 were returned, with 132 of the participating farmers having answered the question for farm-level risks and 104 having given indications of potential adaptation measures and could therefore be used for the purposes of research problems 2 and 3, an evaluation of perceptions of farm-level risks and an assessment of their change over time as well as their conceptualizations of adaptation and the role of risk perceptions for farm-level adaptation decisions. For evaluation of results, raw data were cleaned for semantic similarities in a first step and then assigned to categories of semantically similar meaning in a consistent manner in a second step. This was done to allow for comparisons among the compared social groups and between the two surveys.

3.4 Empirical results

The results presented in the following are based on descriptive statistics of count data that resulted from transferring the qualitative statements to the open-ended questions into categories of semantically similar expressions. These categories were then statistically described and used for conducting the empirical comparisons presented in this section. The presented results are of an explorative nature, related to the use of open-ended questions, and drawn from non-representative samples.

3.4.1 Social representations of climate change

The following figure (Figure 3) presents word clouds of the 16 most frequently encountered contents represented by keywords to give an idea about commonly employed social representations of climate change and to keep the word clouds comprehensible at the same time. Results for the case of farmer school students are depicted in the left figure, the right figure depicts results found for the group of undergraduate students who had no personal experience with farming.

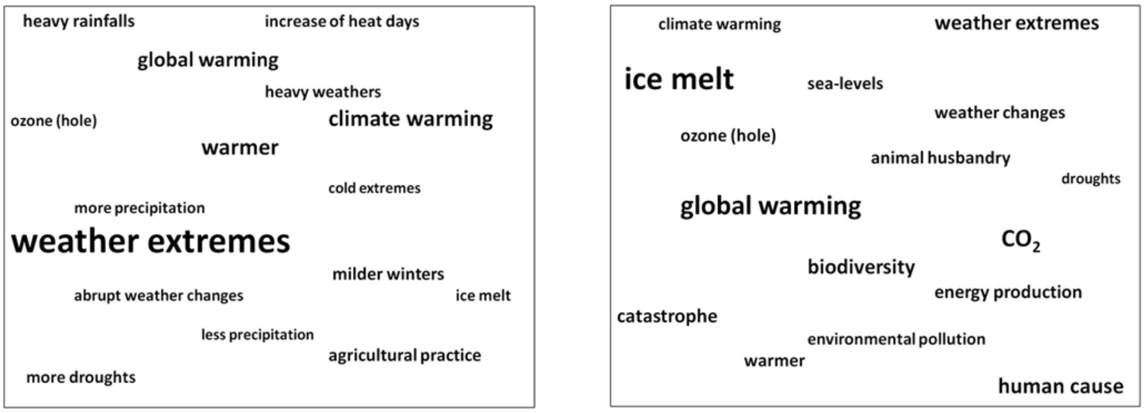

Figure 3: Word clouds depicting keywords for the most frequently encountered associations with the word climate change of farmer school students (left) and undergraduate university students (right)

In the case of farmer school students, 12 out of 16 keywords referred to changes and events that could be experienced in their personal environment, pointing towards a psychologically proximate understanding of climate change. Those keywords are (with shares of individuals in this group that stated associations subsumed under the respective keyword in brackets): Weather extremes (48.1%), warmer (21.2%), increase of heat days (9.6%), more droughts/dry periods (9.6%), milder winters (11.5%), heavy rains (11.5%), more precipitation (7.7%), less precipitation (5.8%), agricultural practice (11.5%), abrupt weather changes (7.7%), heavy weathers (9.6%) and cold extremes (5.8%). Associations with a global scope of reference were "climate warming" and "global warming" that were shared by 21.2% and 17.3% of respondents from the group of young farmers respectively, and "ozone (hole)" or "ice melt", both mentioned by 7.7% of respondents from this group.

For the group of undergraduate university students predominantly keywords with a global or unclear scope of reference were found (13 out of 16), among them (with shares of individuals referencing them in brackets) ice melt (16.7%), global warming (12.4%), climate warming (3.1%), sea level rise (4.3%), CO_2 (9.9%), ozone hole (4.3%), biodiversity (6.8%), energy production (4.9%), animal husbandry (4.3%), environmental pollution (3.1%), droughts (1.9%), catastrophe (5.6%) and human cause (8%). As keywords with reference to the local and personal sphere were counted weather extremes (6.8%), weather changes (3.7%) and warmer (4.3%).

In general, it can be deduced that the conceptualization of climate change was strongly connected with the image of warming in both groups. While word associations mentioned by young farmers predominantly reflected representations of climate change that implied effects on farming conditions and agricultural production or implications for farming practices themselves (e.g. "risks for agricultural production", "time pressure during harvesting time" and "cultivation of new crops") that were subsumed under the keyword 'agricultural practice'[20], for non-farmers only animal husbandry was represented as aspect of farming in their associations. However, this was mentioned most likely in reference to a causing-factor, as implied by the terms "mass husbandry", "animal husbandry" and "animal breeding"[21].

The 16 most frequent word associations mentioned by farmer school students accounted for 87% of all associations mentioned in this group, whereas the displayed expressions only accounted for 58% of all word associations mentioned by undergraduate students. This might be partly due to the fact that the surveyed group of university students was larger than the group of farmer school students (123 vs. 52), but could also be taken as a hint that farmer school students employed a more narrow range of social representations of climate change than student respondents did.

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[20] See Appendix section B1.2.1 for keyword categories applied and B1.2.2 for a full account of farmer school students' word associations.

[21] See Appendix section B1.3.1 for keyword categories applied and B1.3.2 for a full account of undergraduate university students' word associations.

3.4.2 Farm-level risk perception

132 respondents answered the question for significant perceived farm-level risks conducted in 2013, 60 from the Swabian Jura and 72 from Kraichgau region, resulting in response rates of 73.2% in the Central Swabian Jura and 79.1% in Kraichgau, respectively. The following figure (Figure 4) depicts the relative shares of 12 categories of risks (blue) generated from the 303 statements acquired from respondents. It features one generic category as well that is depicted in red and labeled 'weather related risks'. It combines the shares of the three categories 'climate and weather conditions' (13.9%), 'extreme weather events' (10.2%) and 'production risk and production practice' (9.6%), to give a visual impression of the overall magnitude of risks related to climate outcomes in the system of perceived risks that are judged to be significant at the farm level. Statements summarized under these three categories accounted for more than one third (33.7%) of all the collected statements.

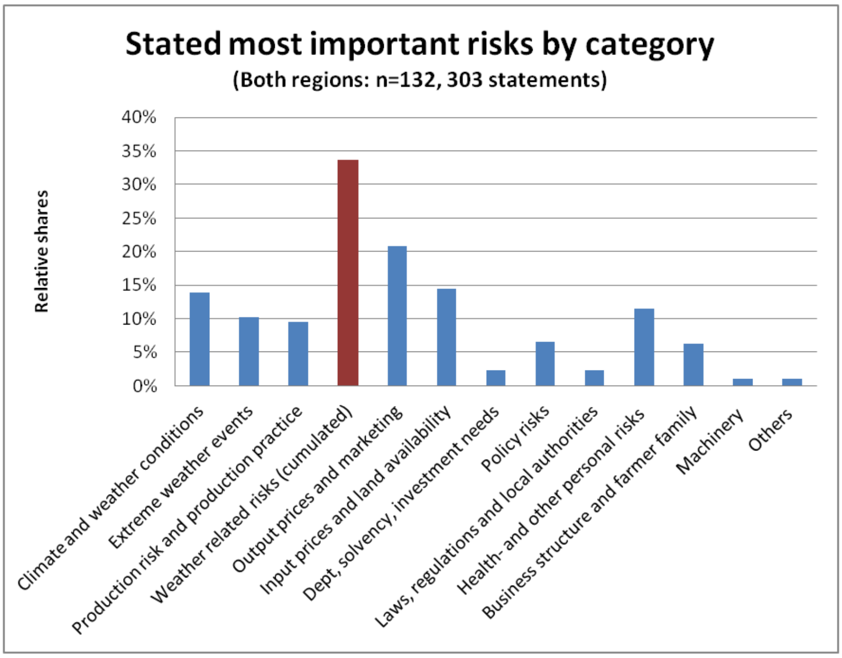

Figure 4: Risk categories based on farmer statements on major farm-level risks in an open question

Respondents viewed as further important sources of risk output prices and marketing (20.8%), input prices and land availability (14.5%), health and other personal risks (11.6%), policy risks (6.6%) and risks related to the business structure and the farmer family (6.3%), the latter category containing statements on the family's acceptance of farming as main occupation, lack of a successor, concerns about hired workforce and a too small farm size, among others[22]. Further risk categories that appeared in smaller magnitudes were risks related to laws, regulations and local authorities (2.3%); dept, solvency and investment needs (2.3%); machinery (1%) and other risks (1%).

3.4.2.1 Signals for climate related risks

Analysis at the statement level permits conclusions about which signals farmers interpret when they form judgments about the significance of farm-level risks. The following figures depict sub-categories that represent semantically similar statements and therefore reflect the wording employed by farmers and the content of raw statements at greater detail than categories based on similar contents of statements, as previously shown. Displayed are the statements that compose the three risk categories attributed to 'weather related risks', 'climate and weather conditions', 'extreme weather events' and 'production risk and production practice'. Frequencies of statements are discerned by region.

The first figure (Figure 5) presents statements that form the category of risks related to 'climate and weather conditions', a category that concerned 28.33% of respondents from Swabian Jura (SJ) and 34.72% of the respondents from the Kraichgau (K) region.

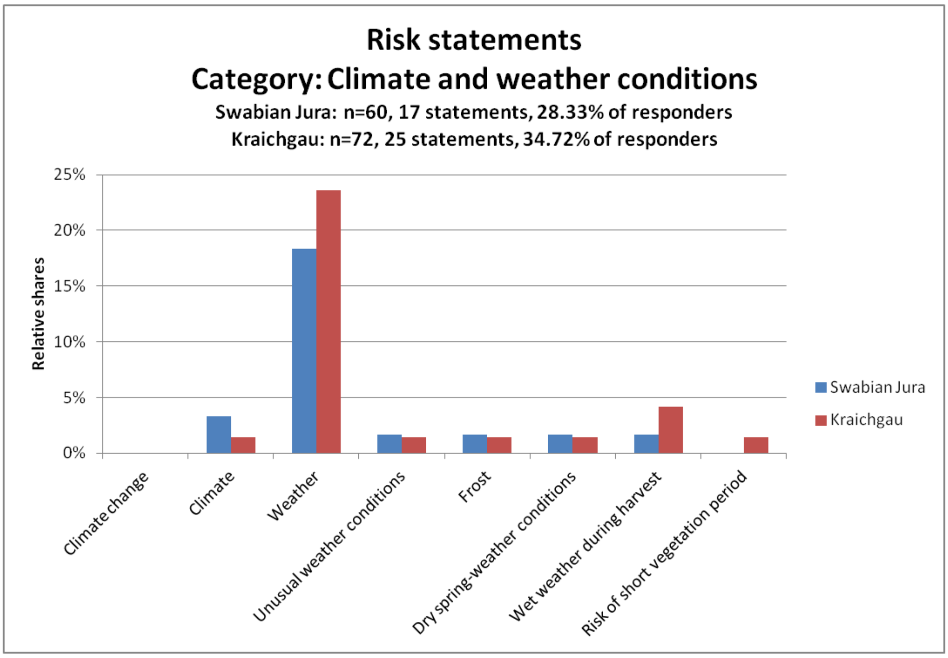

Figure 5: Risk statements listed under the category 'Climate and weather conditions'

As the graph demonstrates, the majority of farmers from both regions that mentioned climate and weather-related risks simply referred to 'weather' in general (K 23.6%/SJ 18.3%). None mentioned the term 'climate change' itself in the context of the question. It must be assumed however, that a share of these statements and, especially statements referring to

22 See Appendix section B2.2 for a full account of statements and assigned risk categories.

'climate' and 'unusual weather conditions' as well as those pointing towards anticipated changes that adversely affect the production cycle ('dry spring-weather conditions', 'wet weather during harvest', and 'risk of short vegetation period') are associated with climatic changes, at least by some of the 8.3% (SJ) and 9.7% (K) of respondents who made these statements.

A total of 24% of the responding farmers mentioned extreme weather events as a significant source of farm level risk. This perception was more pronounced in Kraichgau, where 30.6% of the respondents made statements associated with this category, referring to dry spells (12.5%), hail (11.1%) and heavy weathers (6.9%). In the Swabian Jura these shares were at 6.7%, 6.7% and 1.7%, respectively, with none of the respondents from both regions mentioning 'heat extremes' explicitly, what would have been an outcome expected by the author. These results are depicted in the following figure (Figure 6).

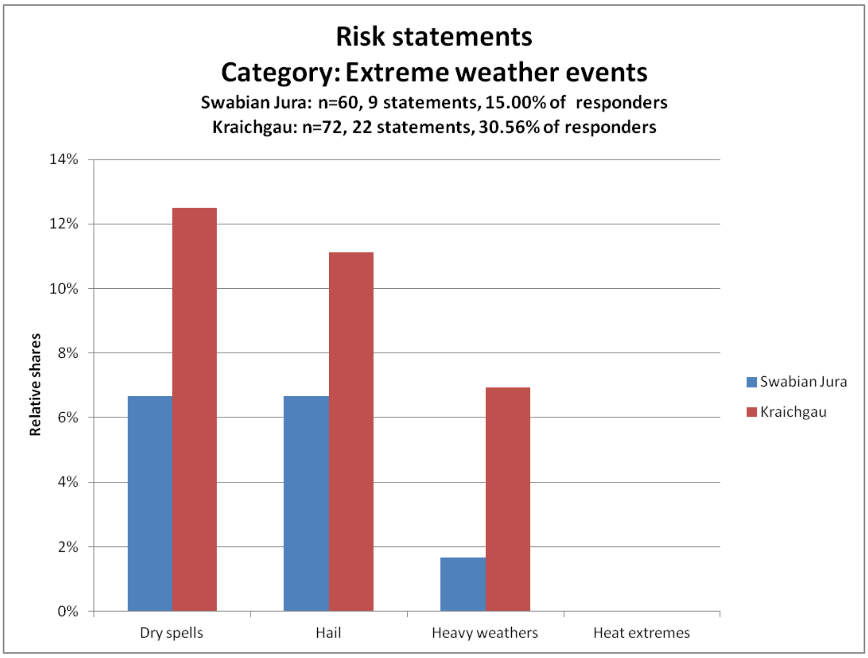

Figure 6: Risk statements listed under the category 'Extreme weather events'

The category of production risk and production practice is presented in greater detail in the following figure (Figure 7). Statements attributed to this category were received from 25% of the responders from Swabian Jura and from 19.4% of the responders from Kraichgau region. Reflecting differences in agricultural practice and environmental conditions, yield losses were an issue of a greater perceived significance in the Kraichgau sample (5.6% vs. 1.7% in SJ), as were risks related to nursing-intensive crops, the selection of cultivars and varieties and the cultivation of specialty crops, which concerned 6.9% of the responders from this region.

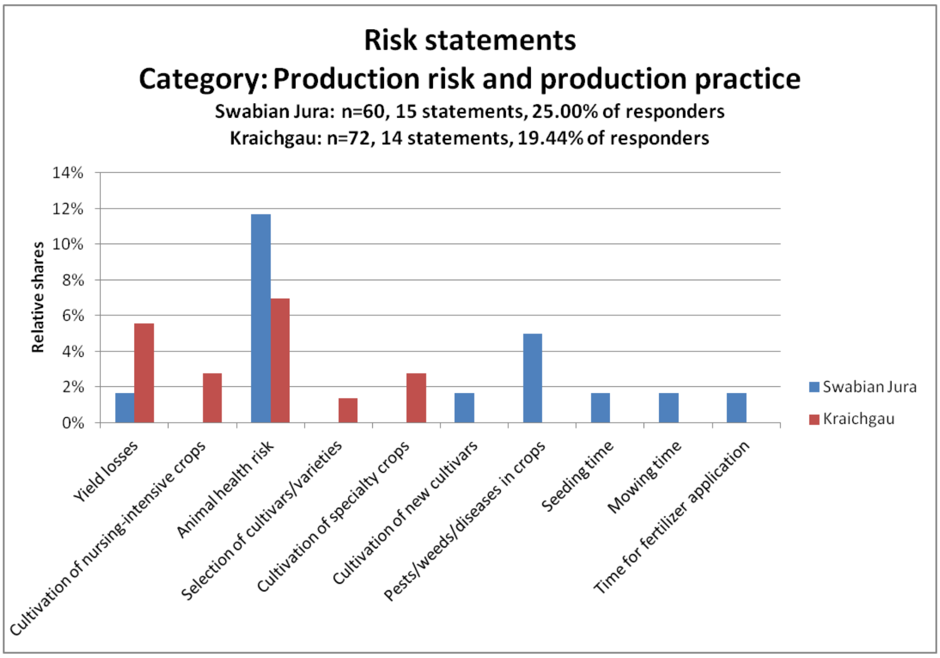

Figure 7: Risk statements listed under the category 'Production risk and production practice'

The majority of respondents from the Swabian Jura who were concerned with risks related to the production base mentioned animal health risks (11.7% vs. 6.9% in K), whereas cultivation of new cultivars (1.7%); pests, weeds and diseases in crops (5%) and the time for seeding, mowing and fertilizer application (1.7% each) represented field level sources of risks for Swabian Jura farmers that also reveal further areas of vulnerability to potential climate change effects.

3.4.2.2 Hierarchies of risk perceptions

The survey question applied in the 2013 study asked farmers to rank perceived risks according to their perceived relevance. The following figure (Figure 8) compares relative shares of the 12 categories of major farm risks (left graph) with relative shares of those categories when mentioned as *most important* farm-level risk, i.e. at first position in the response to the survey question (right graph), both distinguished by region.

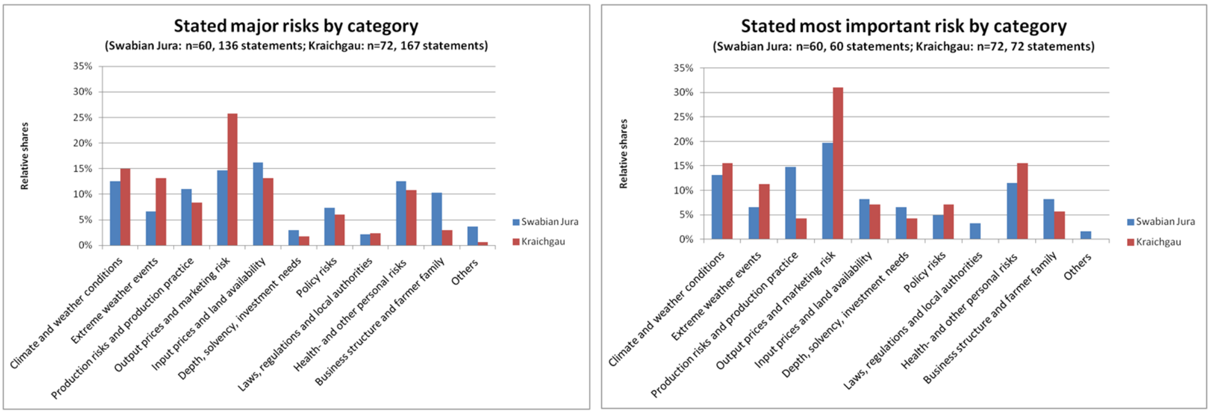

Figure 8: Comparison of relative frequencies of categories for major farm risks (left) and stated most important risks (right)

Comparison of the two graphs demonstrates that output-price and marketing related risks are disproportionately often mentioned as the source of risk perceived as most important, which is also true for the case of health- and other personal risks, at least in the Kraichgau sample, and for risks related to the business structure and the farmer family, in case of the Swabian Jura sample. At the same time, the incidence of input price risk and land availability to be rated as primary source for farm level risk is below the proportion of this source of risk in the statements overall. A closer look into the data revealed that in only 41.2% of the cases when concerns about health and other personal risks were mentioned (i.e. health or outage of the farmer, ageing, work-overload or lack of joy in work), climate related risks were mentioned as well, as opposed to 52.3% in the total sample of farmers. If health- and other personal risks were mentioned the probability of climate and weather related risks to be perceived as source of most important risk was at 14.7%, as compared to 32.6% in the total sample, which points towards a dominating role for perceived health- and personal risks over other perceived risks.

3.4.2.3 Dynamics in risk perceptions over time

The following table (Table 5) compares a set of outcomes of the surveys conducted in 2010 and 2013 at the statement level. As it is unlikely that farmers' duct has changed within this short lapse of time, changes in the frequency of semantics employed in statements are likely due to changes in the perceived urgency and/or severity of the respective risks and therefore reflect changes in the system of beliefs of farmers, i.e. changes in their cognitive systems.

Table 5: Differences in risk statements between the 2010 and 2013 surveys

	2010 (n=53/ 92 statements)		***2013*** (n=132/ total/ 303 statements)	
	Count	**Share in total statements**	**Count**	**Share in total statements**
Weather and climate risk				
Weather (variability)	11	11,96%	39	12,87%
Extreme weather conditions	7	**7,61%**	31	**10,23%**
Climate	7	**7,61%**	3	**0,99%**
Climate change	8	**8,70%**	0	**0,00%**
Market risks				
Fluctuations of output prices (and/or demand)	8	**8,70%**	6	**1,98%**
Declining output prices	2	**2,17%**	30	**9,90%**
Low output prices due to production surplus	1	1,09%	2	0,66%
Market (conditions)	2	2,17%	9	2,97%
Influence of stock market speculations on prices	7	**7,61%**	4	**1,32%**
Input prices, investment costs and profitability				
Input prices	1	**1,09%**	17	**5,61%**
Liquidity	1	1,09%	5	1,65%
Investment risk	2	2,17%	2	0,66%

Policy risk				
(Uncertainties related to) Agricultural policy	9	**9,78%**	14	**4,62%**
Laws and regulations				
Laws and regulations, approval procedures	2	2,17%	7	2,31%
Environmental regulations	1	1,09%	6	1,98%
Structural risks				
Agricultural land prices	1	**1,09%**	23	**7,59%**
Risk of decreasing demand for farm products	2	2,17%	1	0,33%
Food safety issues/scandals	2	2,17%	1	0,33%

The table lists sources of risks external to the farm business and therefore originating from the biophysical or socioeconomic production environment of the farm businesses, as opposed to health- and personal risks and risks related to the farmer family, which have an endogenous character. The following discussion focuses on qualitative inference about trends in these external risks based on semantic differences in the statements and based on their frequencies.

The most evident difference between the two surveys is related to statements containing the term 'climate'. Unless framing- or enumerator effects played a role, urge and significance of risks perceived to be explicitly related to climate decreased between 2010 and 2013, while statements of weather extreme events as significant source of risk increased by about one fourth and the perception of weather (variability) related risk remained within a similar magnitude.

'Fluctuations of output prices and demand' and 'influence of stock-market speculations on prices' were the two sub-categories of statements subsumed under market risks that received most attention in the 2010 survey, representing shares of 8.7% and 7.6% of statements respectively. While frequencies of these statements that indicate concern about risks related to fluctuating output prices declined by a factor of about four ('fluctuations of output prices and demand') and roughly about six in the case of 'influence of stock-market speculations on prices' within the three years in between the two studies, concern about generally declining prices for agricultural products increased by a factor of about 4.5 within the same time. This finding likely is related to recent developments in the socioeconomic environment that occurred shortly before the 2010 survey, i.e. price fluctuations seen in the aftermath of what is now commonly referred to as the world food price crisis of 2008/2009, a Russian export ban on wheat issued in the late summer of 2010 in consequence of sweeping wildfires, and a high level of attention for potential effects of stock-market trade of agricultural commodities for price developments in media coverage during this time. A decreased perceived urgency of these factors is likely reflected by the markedly lower shares of statements referring to these sources of risk found three years after and might be also reflected by increases in attention for other sources of risk in the meantime.

Similar effects are thinkable for the impacts of decreased concern about risks related to agricultural policy and for the effects of an increased level of concern about increasing prices for agricultural land, i.e. a direct effect on the perceived risk related to a recent development or event that is perceived as urgent, accompanied by an indirect effect of dragging attention away from other sources of risk, an outcome referred to as 'finite pool of worry problem' in literature (Hansen et al., 2004; Weber, 1997).

3.4.3 Knowledge and perception of farm-level adaptation measures

3.4.3.1 Elicited categories of adaptation measures

The survey question for potential adaptation measures resulted in 94 measures retrieved from 40 farmers from the Swabian Jura (48.8% response rate), and in 132 measures from 64 farmers located in the "Kraichgau" research region, from where 27 questionnaires were returned without answer on the question (70.03% response rate).

The following figure (Figure 9) depicts relative frequencies of the different categories of adaptation measures found in the two regions. As depicted in the graph, potential reactions to climate change were predominantly understood in terms of possible changes in cropping patterns. This inclination to perceive possible adaptation options primarily in terms of changes in cropping patterns was consistent over both regions (SJ 50%, K 46.2%). With 22.7% of all measures mentioned in Kraichgau and 7.5% in the Swabian Jura, the second most cited category was the area of soil management. A reverse pattern of attention was found for the category of possible changes in fertilizer and pest management, as it was mentioned about four times as frequently by Swabian Jura farmers than by the surveyed Kraichgau farmers (13.8% of statements from Swabian Jura farmers vs. 3.8% of statements elicited from Kraichgau farmers).

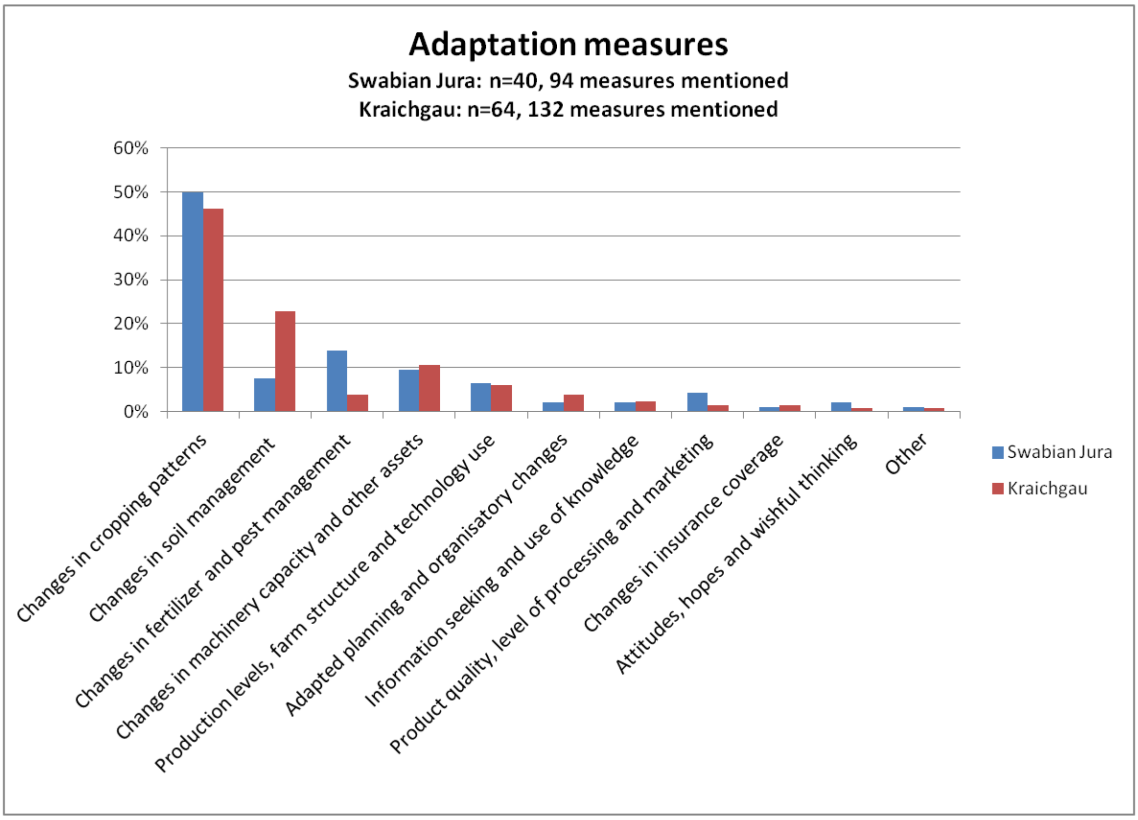

Figure 9: Categories of adaptation measures stated by region

Potential changes in machinery capacity and investments in other assets predominantly related to an increase of readily available firepower when needed (9.6% in Swabian Jura and 10.6% of the answers retrieved from Kraichgau). Similarly, comparable shares of observed answers referred to changes in production levels, the overall farm structure and production technology as potential adaptation measures: 6.4% of the observed answers from the Swabian Jura sample did so, and 6.1% of the ones from the sample of Kraichgau farmers. Indication of measures that fell into the category of adaptations in planning and changed in the organization of on-farm processes (i.e. in the class if merely organizational changes) amounted to 2.1% of the indications received from Swabian Jura farmers and 3.8% of the ones retrieved from farmers active in Kraichgau region. Further categories the observed statements were attributed to were information seeking and use of knowledge (2.2%); changes in product quality, level of processing and marketing (2.7%); changes in insurance coverage (1.3%); the indication of certain attitudes, hopes and wishful thinking (1.3%) as well as of measures or statements that could not be attributed to any of the introduced categories subsumed under 'Other' (0.9%).

3.4.3.2 Mental models of farm-level adaptation

The statements contained in the six largest categories of stated measures and the category 'Attitudes, hopes and wishful thinking' are explored in the following to identify the underlying understandings and ideas about climate change and effective farm-level adaptation to draw conclusions on farmers mental models. Together they account for 95.1% of all statements.

Changes in cropping patterns were named by 70.2% of respondents overall, featuring a share of 75% in the Swabian Jura sample and 67.2% among responses from the Kraichgau. Measures within this class can be subdivided in four categories: The first is made up by statements about using other - new or existing - field crops and varieties or to react via 'adaptations of the crop rotation' to maintain the productivity of arable land under conditions of climatic change. These statements come along with the belief that the genetic potential of existing crops and varieties and of the ones to be developed in the future is sufficient to counteract anticipated adverse effects of climatic changes. Measures that fall under this category accounted for 29.2% of all adaptation measures stated. The second sub-category are changes in cultivation practice intended to maintain yield levels under changing and more erratic climatic conditions, such as to increase the share of winter crops to avoid dry spring conditions, to cultivate early maturing cultivars and to apply variations in seeding rates and seeding time, which made up for about 8% of all measures stated. Extension of crop rotations explicitly mentioned to hedge against climate related yield risk were found to form a third sub-category and accounted for about 12.5% of potential adaptation measures named. Changes in cultivation practice to decrease the impact of changed climatic conditions on the organization of the farm businesses consisted of suggestions to combine cultivars to increase the period available for seeding, harvesting and to avoid labor peaks and made up for a share of 1.3% of all measures.

Changes in soil management were proposed by 27.9% of the respondents, 17.5% in the Swabian Jura sample and 34.4% in the Kraichgau sample. Suggested measures referred to changes in soil cultivation methods aiming to conserve water and to protect against soil erosion. Suggestions were comprised by (among others) minimal tillage, mulch seeding, direct sowing, erosion protection measures and increasing the humus content in soils. These measures made up for a share of 16.4% of all measures stated.

Changes in fertilizer and pest management were predominantly mentioned by farmers from the Swabian Jura, achieving a share of 17.5% of the farmers from this sample, as opposed to 6.3% in the Kraichgau sample, resulting in a share of 10.6% of overall farmers. Measures mentioned in this category can be subdivided into changes in fertilizer management in anticipation of changed nutrient requirements of plants under conditions of climate change (4.4% of all measures stated), increased use of organic fertilization (1,3% of stated measures), changes in spraying patterns in anticipation of changes in the requirements for plant protection measures and changes in spraying patterns in order to save costs (by applying threshold concepts), which made up for 1.8% and 0.4% of the stated measures respectively.

A total of 20.2% of all farmers mentioned **changes in machinery capacity and other assets.** There was almost no difference in popularity found for this type of measure between the two regions, with shares of 20% of farmers referring to them in the Central Swabian Jura and 20.3% in the Kraichgau sample. Suggested changes were capacity related, such as to provide more mechanical capacity, the use of up-to-date machinery and to optimize mechanization, to increase investments into machinery and the use of custom service and to increase firepower via co-operations (6.6% of total statements). Six farmers, all of them located in the Kraichgau research region and two of them occupied with wine production, two with wine and sugar beet production and one with sugar beet and potato production (the sixth farmer made no statement), suggested the installation of irrigation schemes to maintain yield levels, which made up for 2.7% of overall measures stated. Investments in drying facilities and other assets accounted for 0.9% of all statements (two statements) and were also assigned to this category.

Suggested **changes in production levels, farm structure and technology use** were related to an intended increase of farm diversification (3.5% of measures), taking advantage of economies of scale by increasing the agricultural area of the farm (0.4%), the increase of off-farm income and non-agricultural income or to withdraw from farming (1.8%), to save production costs and hedge risk by avoiding big investments or to increase competitiveness by making use of new technologies and innovations (0.9% of all statements each). Measures subsumed under this category were named by 12.5% of the responders in total, by 15% from the Swabian Jura and 10.9% from Kraichgau.

Measures attributed to the category of **adapted planning and organizational changes** accounted for 3.1% of all suggested changes and aimed at the provision of sufficient labor capacity during the year, to avoid labor peaks and account for unfavorable weather conditions in farm planning and to maintain sufficient flexibility in farm organization to react to upcoming conditions and were proposed by 7.8% of the responders located in Kraichgau and 5% of responders from Swabian Jura, totaling up to a share of 6.7% of farmers in the full sample.

Information seeking and use of knowledge was related to looking for information and new solutions if problems come up and to closely monitor market developments or the trust in own professional knowledge and experience, measures that were advocated by 5% of respondents from the Swabian Jura and 3.1% of responders from Kraichgau as suitable adaptation measures, which corresponds to a share of 3.8% of all surveyed farmers.

Attitudes, hopes and wishful thinking. Three farmers altogether (two from Swabian Jura and one from Kraichgau) answered to the question by expressing attitudes, hopes and wishful thinking. Those were to "Be in a balanced relationship with nature" and to "Trust in god" (Swabian Jura farmers) and to "Make a yearly net profit of 100.000€ so that there is no need to worry if something goes wrong" (one farmer from Kraichgau). In how far these statements are related to concrete measures could not be clarified based on the statements given.

Non-response and remarks

With 51.22% the share of farmers that did not state any adaptation measure was about two-fifths above the share found for the case of Kraichgau farmers (29.67%). This result can be taken for an indication of a lower perceived vulnerability, but it could also be an indication for a lower perceived efficacy in the case of Central Swabian Jura farmers. This distinction is supported especially if answers that lacked an indication of possible adaptation measures but came with a remark is accounted for, as depicted in the following table (Table 6). About 2.5% (2.44%) of Central Swabian Jura farmers indicated that they had not thought about adaptation measures yet, that they attribute a minor relevance to climate change as compared to other problems present in farming, or uttered doubts about the reality of climate change in general. For all three opinions these shares were at zero in Kraichgau.

Table 6: Shares of non-responses and remarks to the adaptation question

No measure stated	Swabian Jura (n=82)	Kraichgau (n=91)
Non-response or unclear remark	42.68%	27.47%
"Not thought about yet"	2.44%	0.00%
Minor relevance of CC relative to other concerns	1.22%	0.00%
Skeptical about the reality of CC	1.22%	0.00%
Concern about CC and/or expected consequences	1.22%	0.00%
Concern about CC and/or expected consequences but statement of "no proper measures at hand"	1.22%	0.00%
Uncertainty about direction of CC-effects/uncer-tainty about proper measure	1.22%	2.20%
Total share of participants:	51.22%	29.67%

Remark: CC is used here as abbreviation for climate change. Stated sample size 'n' refers to number of observations in the survey not to shares of respondents to the question.

Also, statements appeared that can be taken as hint for a weak perceived adaptation efficacy. Those were the indication of concern about climate change but to have "no proper measures at hand", given by 1.22% of the Central Swabian Jura farmers, which corresponds to one farmer, but none of the Kraichgau farmers. A similar effect for perceived self-efficacy can be assumed for the opinion that uncertainty about the nature and direction of climate change effects causes uncertainty with regard to the right adaptation measures to be taken, a remark that was found in both regions, in 1.22% of farmers in the Central Swabian Jura and in 2.2% of Kraichgau farmers. The reason why these comparatively low shares (that often are associated with single observations) are discussed, is that they deliver qualitative insights into the variety of mental models present about the challenges posed by climate change, the necessity for- and implications with farm-level adaptation, as well as for reasons that are perceived as obstacles to efficient adaptation by farming practitioners. Moreover, it can be inferred that the indications given partly are as well explanations for the encountered much larger shares of non-responders to this question that did not indicate any additional remark.

3.4.3.3 Determinants of adaptation knowledge

Survey participants stated 1.31 adaptation measures on average. Participants from the Swabian Jura named 1.15 measures on average and survey participants from Kraichgau 1.45. An important factor for this result was that the rate of response to the question was at 70.33% among survey participants from the Kraichgau, and only at 48.78% among participants from the Central Swabian Jura, with responders to the question from Swabian Jura mentioning 2.35 measures on average and those from Kraichgau 2.06. This discrepancy between response rate and amount of measures stated in case of response contributes weight to the question for determining factors for the amount of perceived adaptation options that can be recalled, i.e. adaptation knowledge. To shed light on this issue, standard statistical tests for significance of differences in means (Student's t-test) and for independence of categorical factors in 2 x 2 contingency tables (Pearson's χ^2) were performed on the data. In addition, a generalized linear model was applied to test for association of the categorical *variable main production activity* and the response variable defined as 'number of measures stated', to account for the properties of count data of low magnitudes, which is usually non-normally distributed and for which the Poisson distribution is the reference distribution. A Poisson distribution and log-link function were therefore assumed in the generalized linear model that was implemented under SAS (Version 9.4), using the PROC GLIMMIX procedure.

Region

The difference of mean measures stated by total survey participants due to region of origin (Swabian Jura 2.35, Kraichgau 2.06) was found not to be significant, based on the results of one-sided t-tests. A statistically significant difference for the average number of measures stated by responders to the question from Kraichgau (1.45) as compared to the average from responders from the Swabian Jura (1.15) at a 10% level of significance could be established however[23]. This reflects the effect of the higher share of non-responders to the question in the Swabian Jura.

23 See Appendix section B3.3.1 for results of the statistical tests.

Age of participant and response to the question

No significant difference regarding the mean age of responders and non-responders to the question could be established based on t-tests, neither in the full sample of survey participants nor if distinguished by region[24].

Perception of climate related risks

Having given statements that indicate the perception of climate and weather related risks as defined in the previous section was found to be associated with giving statements of knowledge of adaptation measures at a 5% level of significance, based on χ^2 - tests performed on contingency tables displaying the relationship between these two factors. This feature was found to account for the entire sample of survey participants as well as for both sub-samples of from the research regions independently[25]. The average age of the respondents that perceived climate and weather-related risks was thereby significantly lower in the sub-sample of Swabian Jura farmers than the age of those who did not make this statement, at a 10% level of significance. For the whole sample, as well as for respondents from Kraichgau, a significant difference in mean age in this regard could not be proven[26].

Main production activity

Generalized linear model results indicate a significant effect of the stated main production activities *pork and poultry* (granivores), *grass and other fodder* and *specialty crops and vegetables* production on the average number of adaptation measures mentioned. In all these cases the observed mean of adaptation measures stated was significantly different (higher) from the sample mean, at a 5% level of significance. Significant effects on mean adaptation measures stated could not be established for the other main production activities defined, *dairy and other cattle*, *arable crops* and *other main production activities*[27].

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[24] See Appendix section B3.3.2 for results of the statistical tests.

[25] See Appendix section B3.3.3 for results of the statistical tests.

[26] See Appendix section B3.3.4 for results of the statistical tests.

[27] See Appendix section B3.3.5 for results of the generalized linear model.

3.5 Discussion of results

Social representations of climate change

Word associations collected from farmer school students reveal understandings of climate change that are closely connected with personal experiences acquired through interactions with the biophysical environment that determines production outcomes. This likely reflects a greater exposition to the biophysical environment in combination with usually higher stakes involved if these experiences are made, as compared to members of the general public due to the profession. This might also result in a predisposition of farmers to interpret the experiences in terms of ongoing climatic changes, frequently probably not explicitly questioning the cause, or at least treating this issue as a question of minor relevance. This is reflected by the fact that at least four categories of statements found among the 16 most cited categories ('CO_2', 'energy production', 'animal husbandry' and 'environmental pollution') were concerned with the cause of climate change in the case of university students as compared to none of the categories that were established in the group of farmer school students. At the same time university students were more influenced by images from outside (media) and referring to disastrous but predominantly far-away outcomes

These findings indicate different conceptualizations of climate change and related effects in the two groups. The elicited expressions demonstrate a greater psychological proximity of farmer school students to climate change as compared to young adults of a similar age who display a greater psychological distance via their word associations. The effect of psychological distance has been discussed in literature: Issue-avoidance and resignation may be triggered if climate change is connected to negative and distant associations as and if the issue might be perceived as too overwhelming for individuals to react in an effective way (Moloney et al., 2014; O'Neill & Nicholson-Cole, 2009). A familiarization with climate change caused by repeated personal experiences on the other hand may cause a slow process of 'becoming blind' for the effects of climate change and the potential risks implied in the long-term, especially if changes come slowly and if known and available measures are perceived effective in counteracting expected outcomes. Psychologically proximate conceptualizations may as well lead to an increased level of alert and risk perception if certain events and related outcomes are observed. This is especially likely in cases when effects attributed to climate change come along with financial losses of great magnitudes and without easily accessible cures. This might be a reason why extreme weather events played such a prominent role for the conceptualization of climate change found in young farmers, as well as for risk perceptions elicited from experienced farmers.

Weather and climate related risk perceptions

Weather- and climate related risks account for the major share of perceived risks at the farm level, a characteristic that increased over the time in between the two surveys and is even magnified if secondary effects are included (i.e. perceptions of production risks that may be partially be due to climate change effects on animal diseases and pest pressure) even though explicit mentioning of 'climate change' as a source of risk has vanished from the records in the second study. The sub-categories of statements referring to 'weather' and 'extreme weather events' were accounted for the greatest share of statements in this category and were especially important for Kraichgau famers. Even though they are not explicitly linked to climate change, analysis of semantics at the statement level, as for instance implied in statements such as "unusual weather" (farmer from Central Swabian Jura in the 2013 survey), or "the weather is always extreme" (farmer from Central Swabian Jura in the 2013 survey) nevertheless suggest that these risk perceptions are viewed in the context of an ongoing climatic change, at least in parts of the farmer population.

Analyzed at the statement level, a comparison of the two samples further delivers indications for certain dynamics in risk perceptions: While statements related to developments that currently received a great degree of public attention - such as potential adverse effects of stock-market trade on prices for agricultural products or foreign export bans - those topics had disappeared from the records in the second survey, conducted less than three years later. Also, no explicit statements of "climate *change*" as source of major risk were found anymore in the second survey. The question that matters in the adaptation modeling context is if this result is an indication of an - on average - higher climate change awareness of the farmers surveyed in 2010, likely related to 'recency bias' and some previously observed events or social discourse on the topic. In general these findings might relate to a phenomenon referred to as "*finite pool of worry-problem"* (Hansen et al., 2004; Weber, 1997) in cognitive science, which could as well potentially affect adaptive behavior. The underlying reason has been identified to be related to a limited capacity of the cognitive system to simultaneously deal with several concerns, which requires focusing on one or a few perceived risks, as coping strategy (Hansen et al., 2004; Weber, 2010).

As a possible conclusion it can be assumed that in addition to changes in the frequency of occurrence and strength of personal experiences with climate outcomes and the influence of social interactions for interpreting those experiences, recent developments in important fields of farm level risk also influence the perception of climate and weather related risks and probably the level of alert and readiness to react to the expected outcomes of an anticipated ongoing (anthropogenic) climate change.

Adaptation knowledge

Climate change effects currently seem to be perceived mainly in terms of problems that can be counteracted by short-term changes in agricultural practice, such as in crops and cultivars produced, as in total about 70% of the respondents made the respective statements, changes in cultivation practices (27.9%) and input management (10.6%). Merely intended changes in machinery and capacity of other assets (20.2% of farmers) predominantly intended to counteract the effects of increased weather variability and incidence of weather extremes such as drought periods are changes among the frequently mentioned measures can be expected to come along with increased investment costs, at least partially, in cases the intended capacity increase is not covered by custom service or if irrigation schemes are envisaged. Major changes in farm organization such as investments in new branches, increase agricultural area to make use of scale-effects, increase the share of off-farm income or to abandon farming altogether were not among the most prominently cited measures, as less than 5% of the respondents took them into consideration. The preference for smaller changes could be rooted in low initial costs and lower cost increases per-se, a usually higher degree of revocability as compared to long-term measures in combination with doubts about the existence, direction and persistence of climatic changes. Relevance of this uncertainty for adaptation knowledge is supported by the markedly lower response rate among Swabian Jura farmers, where climate signals might be less pronouncedly pointing in a certain direction, as the region generally experiences lower yearly average temperatures and harsher climate than the Kraichgau.

This difference in response rate had a significant effect on the difference of mean adaptation options know per farmer, with 1.15 measures mentioned in Central Swabian Jura, and 1.45 in Kraichgau. Further significant influence for the number of adaptation options named was found for the major production activities pork or poultry production and grass and other fodder crops and for specialty crop and vegetable production. In the first two cases this might have been caused by more cognitive effort spent on thinking about adaptation in if solutions are not as obvious and easy to implement as in the case of arable production, which can be expected for production related on grassland and climate management in stables. For the latter case it is likely that a higher vulnerability of specialty crop and vegetable production induces a higher awareness about adaptive reactions. On a personal basis, the perception of climate related risks was significantly related with the propensity to know something about adaptation measures, i.e. to having thought about this issue, which is in line with the discussion in Arbuckle, Morton, & Hobbs (2015) about the effects of perceived climate related risks.

3.6 Conclusions

Signals for weather changes are received from the biophysical environment. Even though statements are not always explicitly related to climate change, farmers consider reactions to climate change. Analysis of perceived sources of risk in combination with social representation found in young farmers and an evaluation of the considered adaptation measures indicate that climate change in the perception of farmers predominantly is related to increasing incidence of draught periods and other weather extremes, as well as to an increased weather variability as well as with the consecutive farm level-effects. Adaptive response in consequence is predominantly associated with short-term changes in production practice and farm organization. Overall it can be deduced that climate change is anticipated to interfere with the productive capacity of arable land through impacts on soil characteristics and on growing conditions during the production cycle. It is further expected to affect work organization, to increase the optimal level of provision of labor and machinery capacity and to increase income variability and uncertainty related to investments. The effects of climate change are assumed to be compensated predominantly by changes in practice at the field-level and with the provision of increased flexibility with regard to labor and machinery capacity to provide increased firepower when needed.

4 Experimental Elicitation of Patterns of Expectation Formation

The study presented within the following chapter is based upon an experimental approach designed to elicit patterns of expectation formation in the context of climate change and farm decision making. It has been implemented with experienced farming practitioners (n=15), young farming practitioners from farmer technical and master schools (n=17), and young academic professionals in the field of agriculture that were university students enrolled in agricultural study programs at the University of Hohenheim (n=65), in a series of computer-lab sessions conducted from 2013 to 2015. The experimental task can be described in a stylized way by being comprised of the consecutive steps of (1) reception of a climate signal that is part of a sequence of related signals that depend on the simulated climate, (2) internal processing of information and formation of judgments based on the observed conditional information, and (3) the display of a behavior in terms of monetarily incentivized economic choices framed as agricultural land-use decisions. Inducing this sequence of processes via computer lab-based experiments allows for observing 'behavioral' aspects of individual economic decision making and for analyzing the retrieved data for the existence of heuristics and biases that may interfere with the assumption of rationally optimizing actors that has oftentimes been imputed in standard economic models. A specifically developed procedure allows for the identification of a number of biases and heuristics that underlie the revealed expectation formation mechanisms.

4.1 Introduction

From a 'technical' point of view, climate denotes the statistical probability of weather events at a certain location and comprises a substantial part of the production risk of a farm decision maker. The standard tool for modeling decisions under uncertainty in economics has been the expected utility theorem (Friedman & Savage, 1952; Meyer, 2002; Neumann & Morgenstern, 1947; Schoemaker, 1982). According to it, decision makers prefer the alternative with the highest probability-weighted utility, given their individual risk preference. To calculate expected utility however, the decision-maker must have an idea of the probabilities associated with the occurrence of the possible decision outcomes (Hardaker, Huirne, Anderson, & Lien, 2004; Hardaker & Lien, 2010). The rational expectation hypothesis assumes that an economic decision-maker would make use of a rational procedure to combine all pieces of information available when forming expectations (Muth, 1961). While individual expectations may still differ due to individual errors, they can be expected to be normally distributed around – and thus on average coincide with – the “objective” expectations. Any deviations would be non-systematic with respect to the available information and an objective model of reality (Shaw, 1987; Tesfatsion, 2006). Following this principle, economic research has traditionally treated subjective probabilities as equal to objective probabilities (i.e. probabilities derived from statistical analysis) (Hardaker et al., 2004; Ogurtsov, Van Asseldonk, & Huirne, 2008; Shaw, 1987).

Thanks to the work of psychologists, first and foremost Daniel Kahnemann and Amos Tversky, economists have now largely accepted the idea that economic decision making is not solely subject to rational considerations but also to a number of deviations from rationality concerning probability judgments, as well as other features of decision making. These are rooted in psychological pitfalls that are often due to limitations in perception, cognitive capacity and cognitive processing. Kahnemann and Tversky identified three types of heuristics individuals frequently employ to reduce the complexity of the task of assessing probabilities of decision outcomes (Kahneman & Tversky, 1972; Tversky & Kahneman, 1974): (i) People tend to judge the probability of an object belonging to a class by its resemblance to existing stereotypes of the class, ignoring much more relevant information like prior probabilities, sample size, predictability, and expected accuracy of predictions *(Representativeness heuristic)*. (ii) People tend to estimate frequencies of events based on the availability of information about them, i.e. they are likely to overestimate the probability of events that are easily remembered *(Availability heuristic)*. (iii) People tend to form an initial opinion based on prior information or incomplete assessment and subsequently use these initial assumptions strongly when adjusting opinions after new information is obtained (*Anchoring and adjustment heuristic*). As a special case, ignoring additional information or selectively interpreting it to confirm the view once held leads to C*onfirmation bias* (Rabin, 1998).

In the meantime, findings from brain science and cognitive science have revealed the physiological side to at least some of the frequently found violations of rationality: Information from own experience and statistical information are processed through different processing systems in the human brain. Information from own experience is processed via the experiential processing system and related experience-based learning is frequently connected with the memory of feelings (such as concern, fear, joy, awe, etc.). Therefore, it is often related to the fast and automatic perception of affect and the perceived need for immediate action (Marx et al., 2007; Slovic, Finucane, Peters, & MacGregor, 2004; Weber, 2010). Information based on statistical description (usually provided in the form of statistical summaries and numerical descriptions of probability distributions) on the other hand is processed via the analytic processing system. The capacity for analytic processing must be acquired. It further requires cognitive effort and is shaped by knowledge, training, and cognitive capacity (Weber, 2006, 2010). For this reason, the capability for processing of statistically described information may greatly differ among individuals.

Due to their relation to the emotional system, information resulting from personal experience or vivid descriptions of other peoples' (even hypothetical) experiences often dominates statistical information when individuals make probability judgments (Marx et al., 2007). The experiential processing system however typically neglects concepts such as relative frequency and sample size, a feature of the heuristics and biases described by Kahnemann and Tversky. For this reason, the perception of - and judgment on - the gradual and long-term process of climate change is often heavily influenced by an individual’s memory of recent or exceptional years, rather than by scientific information. This is despite the fact that statistical analysis of longer time series and projections would be much more rational (Marx et al., 2007; Weber, 2010). Moreover, research in social science has pointed to the importance of cultural values, personal identity and worldviews for shaping the perception and processing of probabilities of climate related events. For example, Weber (1997) observed that Illinois farmers' memory of recent years' weather conditions was significantly influenced by whether they believed in the existence of climate change or not.

The importance of experiential information, cognitive biases and shaping by social norms implies that individual probability distributions - and as a result, expectations - cannot be equated with objective probability distributions and expectations. Empirical evidence confirms that the actual patterns of expectation formation are heterogeneous among individuals within society (Just & Rausser, 2002). These findings raise the question to what extent heterogeneity in expectation formation influences economic decision making in general and in the context of climate change adaptation in particular. Traditionally, scientists have tried to indirectly derive expectations from observed (i.e. real world) economic decision making (Hey, 1994; Just & Rausser, 2002). However, doing so depends on crucial assumptions concerning the underlying model of behavior. Therefore, the analysis effectively constitutes a joint test of the hypothesis of behavior and of the model of expectation formation. As a consequence, different models of expectation formation can only be contrasted and compared when direct observations of expectations are available (Just & Rausser, 2002; Nerlove & Bessler, 2001; Pesaran, 1987). While direct observations of expectations can usually not be found in secondary data, they can be generated in experiments.

4.2 Method

Experimental approaches have been successfully applied within several disciplines to explore implicit patterns of behavior and have been proposed as especially useful to inform agent-based models with empirical data to calibrate the decision functions used with revealed behavior (Heckbert, Baynes, & Reeson, 2010). Lab experiments allow for setting the decision parameters equal for all participants by creating a controlled decision environment. They further allow for simulating circumstances, for instance magnitudes of change of production parameters that have not been observed in the real world, reactions to which cannot reliably be evaluated by use of standard survey approaches that would rely on highly hypothetical questions in these cases. Laboratory experiments are distinctive from other techniques to inform agent-based models as, for instance, companion modeling (Voinov et al., 2016; Voinov & Bousquet, 2010) in the sense that they are usually highly abstract and controlled in order to test certain, clearly defined hypotheses of human behavior in very specific decision-making situations (Heckbert et al., 2010).

4.2.1 Design

Reflecting a real-world decision situation of major relevance for MAS/LUCC applications of MPMAS, the experiment was designed to mimic the decision problem of agricultural land-use adaptation in response to climate change and the related uncertainty. Therefore, the dependent variable was selected to be farm profit under the circumstances of uncertainty about climate outcomes. The decision problem was implemented as optimal crop choice for several plots of land under uncertainty about the weather conditions during the growing season to come. The experiment had to run over several consecutive periods under changing climatic conditions and sequentially accumulating information on the state of the present climate, so that expectation formation patterns could be tracked. In every period, participants had to choose a combination of four crops for five plots that had ten hectares each and represented the arable land of their virtual farms. All combinations were possible, and participants were told that the experimental setup abstracts from crop rotation constraints and regulations related to agricultural policy. The experiment was designed to run over 20 consecutive periods that were referred to as 'years', which participants were aware of from the beginning.

In the initial setting of the experiment only “good” and “bad” weather outcomes were possible to occur. In a later phase of the experiment also "very bad" weather outcomes were possible, which affected the gross margins to be expected from the plots in the way depicted in the following table (Table 7). Crop choices had to be made at the beginning of each year, i.e. before the weather condition of the year was determined by the experimenter by means of a blind draw, conducted in front of the participants. Yearly farm income was therefore determined by the combination of crops chosen and the weather outcome of the cropping season the choice was made for, minus an amount of 10 000€ representing yearly expense for business maintenance and living cost. This subtracted yearly amount was held stable over the course of the experiment for reasons of simplicity. These conditions were introduced by displaying and explaining Table 7 at the beginning of the experiment, as well as the interactive form *cropping plan* and the automatically generated result sheet *yearly income sheet*[28], that were used to capture participants' decisions and expectations and for presenting and documenting outcomes.

[28] See Appendix sections C2.1 and C2.2 for the respective forms.

Table 7: Cropping options and related per-plot gross margins under the respective yearly weather conditions possible during the experiment

Cropping option	*J*	*K*	*B*	*L*
Gross margin per plot (10ha) in a year with "good weather"	16 000€	12 000€	8 000€	5 000€
Gross margin per plot (10ha) in a year with "bad weather"	- 4 000€	- 1 000€	2 000€	4 200€
Gross margin per plot (10ha) in a year with "very bad weather"	- 5 000€	- 3 000€	1 000€	4 000€

The per-plot gross margins were stipulated and not based on real data. This was done for two reasons: First, not to introduce bias through association of the values with real crops, and second to use figures that serve the needs of the experiment with regard to dissimilarity to each other and the risk characteristics of the crop choices. Probabilities for the respective weather outcomes were communicated via ten balls that had two different colors and symbolized good weather (green) and bad weather conditions (red) of a crop year. The balls were contained in an urn (an opaque black bag was used for this purpose) from which random draws were conducted. After the experimenter determined the weather condition of the actual crop year, the ball was placed back into the urn, so that the composition of the distribution did not change due to the draws conducted.

In order to comprehend implicit, experience-based expectation formation about changing climate and to capture the effect of uncertain climate on risk-level choices, the distributions of possible weather outcomes changed during the experiment, from a distribution that consisted of five red and five green balls and was communicated to the participants to be in play *for sure* during a first phase of the experiment, to one that either consisted of four red and six green balls or six red and four green balls, both to occur with the same probability, in a second phase[29]. Each of these two distributions was to occur with the same probability of 0.5, which was demonstrated via a double-blind selection of the climate to be in play

29 Climate change as aspect of the experiment as well as the composition of the two distributions possible with climate change were introduced before the actual conduction of the experiment and referred to as ‘advantageous’ and ‘disadvantageous’ climate. Nevertheless, the *time of occurrence* of this change in year six was unforeseen for participants.

after climate change set in. This was conducted in advance to the experiment by the experimenter and an assistant, as well transparently in front of the participants.

While participants had been informed in advance about the composition of the two possible climate distributions to be under effect after the change, their equal probability of occurrence and that climate change is going to happen in the course of the experiment, they did not know in advance in which year it would occur. Only after the elapse of year five they were told and demonstrated that the distribution used in the first phase was put aside and the formerly selected bag was now used for conducting the draws[30]. In a last unforeseen change, the possibility of extreme events was introduced by adding two yellow balls at the beginning of round 16 to the distribution in play which were referred to as 'very bad weather outcomes'. This procedure resulted in the possible compositions of weather distributions representing climate that characterized the three phases of the experiment depicted in table 8 (Table 8).

Table 8: Phases of the experiment and possible distributions that represented climate

Phase of experiment	*1*	*2*	*3*
Round ('Year')	1-5	6-15	16-20
Climate applied	5 good/5 bad	6 good/4 bad *or* 4 good/6 bad	6 good/4 bad *or* 4 good/6 bad + 2 very bad
Certainty about climate	yes	no	no

Because yearly earnings based on the decisions added up over all periods and were monetarily incentivized[31], participants could experience the effect of a changed composition of the distribution in combination with repetitive random drawing and thereby *learn* about the impacts of these characteristics on their income and overall wealth. The effects mimicked via this procedure therefore resemble the effects of climate variability and climate change under real world conditions.

30 To ensure credibility in the experimental procedure, the bag was selected from two neutral bags in a double-blind procedure before the experiment after showing the participants the bags' contents, via tossing a coin and selecting one of the two bags accordingly. This procedure was conducted under the eyes of the participants.

31 Monetary payouts were proportional to the wealth acquired in the course of the experiment. Farmers and farmer school students were refunded with 1€ per 10,000 monetary units gained during the experiment, and academic scholars at a rate of 0.33€ per 10,000 units earned, in order to reflect differences in opportunity costs and reference incomes.

4.2.2 Conducting the experiment

The experiment was extensively tested and discussed with peers, non-scientists and students in advance to the conduction of the actual session, first in a paper-and-pencil version, later in the computer-based version.

4.2.2.1 Selection of participants and implementation of experiments

Full random versions of the experiment were implemented with 15 experienced farmers from the research regions Kraichgau and Swabian Jura who participated in a stakeholder dialogue session of the FOR 1695 research unit that was conducted at the University of Hohenheim in 2013, and with 17 young farming practitioners from a farmer school close to the Central Swabian Jura research region in 2015. In both cases, the total number of participants was divided into two sub-samples prior to conducting the experiment, in order to get a greater number of observations for different climate trajectories.

Implementing this approach resulted in four random sequences of weather outcomes, one from each session. Each of the four random sequences was then re-applied in a repetition session with a total of 65[32] academic scholars enrolled in agricultural study programs at the University of Hohenheim, to increase the number of observations available for each sequence and to test for differences in expectation formation behavior between agricultural experts that gained their experiences in the field, and University educated agricultural experts.

The original sequences generated during the sessions with farming practitioners that were based on random draws were replicated in the experimental sessions with academically educated agricultural experts for reasons of comparability of results. However, in these sessions it was made sure as well that the participants understood and accepted the genuinely random character of the sequences and the randomness of the processes involved, by demonstrating the random procedures that generated the outcomes.

4.2.2.2 Technical implementation

The computerized version of the experiment was implemented using a client-server architecture, based on an Apache/MySQL/PHP solution. Each subject used a separate computer with a standard web browser to access the forms provided by a central server. For reasons of transparency and understandability, weather realizations were not generated by a computer, but determined via draws from an urn in front the participants. Demonstrating the random nature of the weather realization was found to be necessary during pre-testing, as participants might otherwise have anticipated a certain sequence created by the experimenter and adjusted their expectations accordingly. In the groups of students used for repeating the experiments and as control group detailed explanations and exemplary demonstration of the random processes that yielded the sequences were provided. Accordingly,

[32] One academic participant did not finish the experiment due to 'bankruptcy' during the experiment and was therefore not accounted for in the analysis.

the sequences as well as other experimental conditions except the actual random determination of the weather outcomes were identical. In these sessions instructions also followed a standardized protocol[33]. It was assessed after all experimental sessions (random as well as repetitions) how well the explanation of the random procedures involved and the experiment itself was understood by means of a paper-based questionnaire.

Each of the experimental years consisted of the following sequence of steps through which participants were guided by the web interface and the experimenter:

1) Data entry by participants

Participants had to choose the crops for their five plots for the coming year, state which weather they expected for the next year and – form year 6 on – which weather distribution (i.e. climate) they believed to be 'in play'. For both expectations, they had the option to select “no statement possible”.

2) Determination of the weather for the actual year

This was conducted by an assistant of the experimenter by drawing one ball from the neutral, opaque bag in front of the participants. The assistant then entered the result into the system. Subsequently the ball was put back into the bag. The procedure was explained beforehand and according to a standardized protocol in a way that it was easy to understand and made the mechanism and the tasks to fulfill obviously clear for participants. Also, the elapse of the experiment followed a standardized protocol[34] in all the sessions.

3) Update of individual incomes and wealth status

Combining participants’ crop choices and the weather realization entered by the assistant, the central server then computed the individual incomes and updated the wealth status of the participants. The personal screens of participants consecutively displayed the obtained income and wealth, the weather realization of the actual year, as well as an overview of the previously realized weather outcomes and individual gross-margins earned on a yearly basis. The current weather outcome as well as previous weather outcomes were also projected on a large video screen in the lab. Individual forms to be filled in at the beginning of each year *('cropping plans')* featured cropping options, fixed yearly expenses, total current wealth, as well as an overview of previous years' weather outcomes, the individual’s cropping decisions and corresponding incomes earned (i.e. this part referred to a farm decision maker's memory or book-keeping, respectively). The form *'yearly income sheet'* that appeared on the individual browser interface after each year's weather realization additionally contained gross margins and the total net income of the year earned from the cropping decision taken and a display of the weather outcome of the production year. Participants were told to take decisions individually during the experiment and without communicating to each other.

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33 See Appendix sections C1.1 and C1.2 for wording protocols applied.

34 See supplementary materials for a detailed description of the procedure of random determination of weather conditions.

4.3 Analysis of experimental outcomes

Conducting the experimental sessions yielded 1,940 combined observations of weather realizations due to random draws, crop bundles chosen by participants and statements of weather expectation, as well as a total of 1,455 observations of statements on expected climate to be present.

4.3.1 Outcomes of random procedures

Outcomes of the Random Procedures

Random determination of the climate to be in force resulted in the selection of adverse climate for three out of the four experimental sessions (Sessions A-C) and only one session for which good climate was selected (Session D). Random sequences of weather outcomes that resulted from the experimental procedures are displayed in the following figure (Figure 10). Following the setup of the experiment, green symbolizes a good, red a bad, and yellow a very bad weather outcome in the respective crop year.

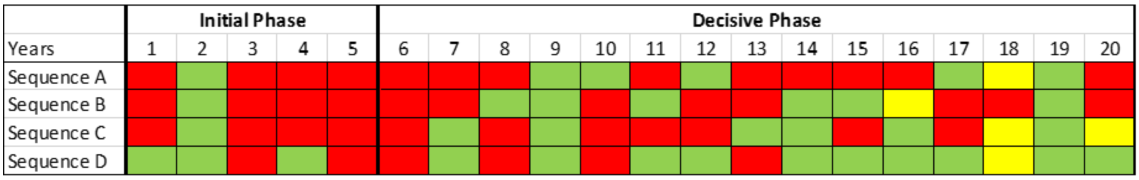

Figure 10: Sequences of weather outcomes that resulted from random procedures involved with the experiment

Posterior probabilities

For each of the observed sequences the probability for the possible climate conditions (favorable/adverse climate) to be in use after climate change set in can be calculated taking into account the observed evidence in terms of observations of weather outcomes for every ‘year’ (i.e. round) of the experiment applying Bayes' theorem. This probability is referred to as posterior probability. Posterior probabilities were implemented by calculating the probability for the distribution that represented adverse climate to be in use at the time of stating the crop choice, given the observed sequence of weather outcomes at any point of the experiment. The observed number of “bad” weather outcomes k in n cropping years of the experiment (i.e. the frequency of k red balls in n random draws) was taken to calculate the posterior probability for the unfavorable distribution to be in use, $P\ (adv|\ k;n\ )$, to do so:

$$P(adv|k;n) = \frac{P(k|n;adv)\,P(adv)}{P(k|n;adv)P(adv) + P(k|n;fav)P(fav)}$$

With:
P (adv|k;n) = posterior probability that adverse climate is present given a number of k draws of "bad" weather outcomes among n total number of observed draws
P (adv) = prior probability for adverse climate to be present
P (fav) = prior probability for favorable climate to be present
P (k;n|adv) = conditional probability for adverse climate
P (k;n|fav) = conditional probability for favorable climate
k = number of draws of "bad" weather observed
n = total number of outcomes observed after the onset of climate change

Because the choice of the climate to be present resulted from the toss of a fair coin, an unbiased (and therefore equal) prior probability for the occurrence of favorable and adverse climate of $P(fav) = P(adv) = 0.5$ could be assumed. Following this procedure of calculation, the probability for observing *k* bad weather realizations given *n* draws $P(k|n)$ is binomially distributed and results from the formula:

$$P(k|n) = \binom{n}{k} p^k (1-p)^{n-k}$$

with probability for "bad" weather *p* being 0.6 in case that the draw was made from the adverse distribution, and 0.4 in case the observed draw resulted from the distribution that represents favorable climate. The posterior probability for favorable climate to be in play $P(fav|k;n)$ results then from $1 - P(adv|k;n)$.

The blue line in the following figure (Figure 11) depicts the development of the posterior probability for presence of adverse climate over the course of the experiment for each of the observed sequences. The dots on the blue line mark the posterior probability at the *beginning of the respective years*, i.e. after the weather outcome (represented by the colored square above) has been determined. The dashed line marks equal posterior probabilities for both possible climates.

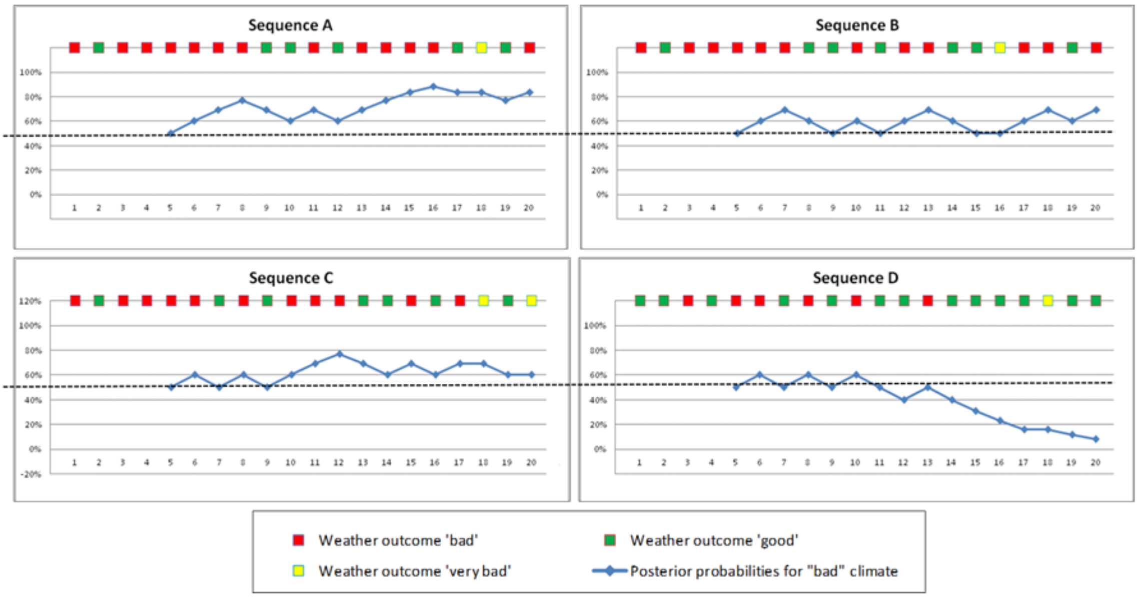

Figure 11: Posterior probabilities for adverse climate in the four random sequences that resulted from repeated random draws in the experimental sessions

As depicted in the figure above, evidence pointed rather clearly toward adverse climate in sequence A, with the posterior probability for adverse climate oscillating between 60% and 77% in between the first draw after climate change set in (i.e. year six) and year eight, and between 77% and 88% in the last seven years. Evidence for adverse climate was less clear in sequences B and C however, where posterior probabilities oscillated between 50% and 69% (B), or reached roughly 80% only once throughout the whole phase with uncertain climate in sequence C. Sequence D resulted from the only session among the four conducted for which favorable climate was randomly selected. Random draws from this distribution resulted in a rather clear signal for favorable climate as from year 14 onwards only green balls were drawn, except one outcome of very bad weather in year 18 that did not change the posterior probability for each one of the possible climates to be present, at least not if rationally judged. Accordingly, the posterior probability for bad climate decreased to about 10% by the end of the experiment.

4.3.2 Statements of climate expectation

The following figure (Figure 12) gives an impression of how the observed statements of climate expectations co-varied with the calculated posterior probability for bad climate to be in force in the different sessions (blue line).

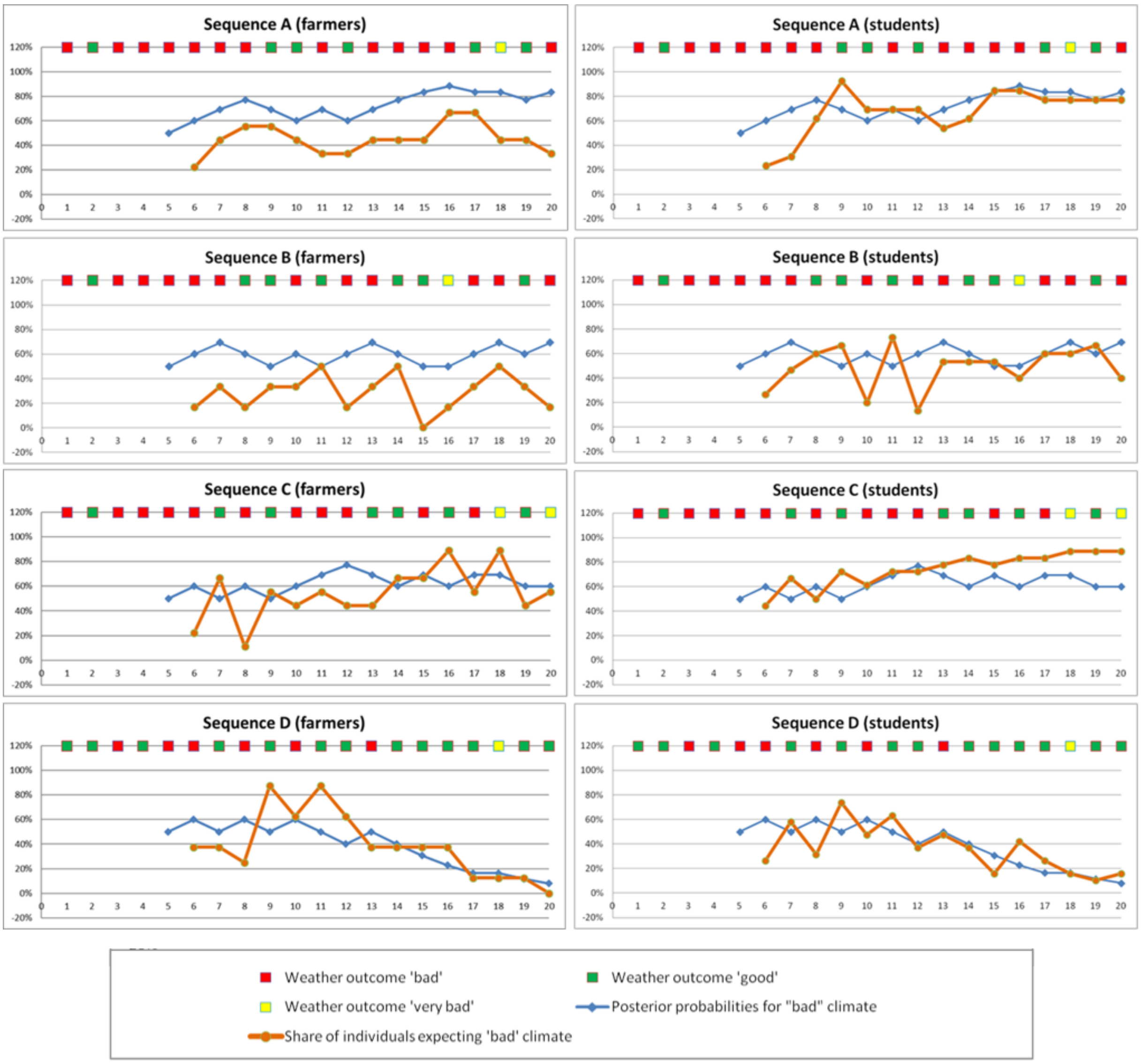

Figure 12: Expectation statements aggregated by sequence and participant status over the course of the experiment

Remark: In sequences C and D ‘farmers’ refer to young farming practitioners from farmer schools.

In addition, the share of individuals stating to expect bad climate to be in force (orange line) is depicted in combination with this posterior probability, differentiated by sequence and participant status. Visual inspection of the graphs allows for the following conclusions about aggregate expectation formation behavior in the groups of participants: (i) In the two groups of experienced farmers that received bad climate, the share of individuals expecting bad climate to be in force drops towards the end of the experiment, even though the posterior probability increases. (ii) The share of individuals that made statements closer in line with the posterior probabilities for bad climate calculated according to the Bayesian principle of information updating on average seems to be higher among academic scholars (right side of the graph) than among farming practitioners from the two research regions (left side of the graph), except for the group that received Sequence B for which the graph shows greater deviations and more similarity to the results retrieved from the sessions conducted with farmers.

4.3.3 Risk level choices

The monetary payout scheme implemented in the experiment rewarded outcomes of crop choices to incentivize meaningful choices. To draw conclusions on the efficiency of the mechanism to induce meaningful expectation statements as well, compliance of statements of climate expectations and risk level choices were evaluated. To do so, a rank sum measure was implemented to reflect the level of riskiness of the crop choices relative to each, as depicted in the following table (Table 9).

Table 9: Defined rank sum values for respective cropping options

Choice option	J	K	B	L
Risk rank of single crop	4	3	2	1
Rank sum of pure bundles	20	15	10	5

Remark: Higher values reflect a higher risk level in terms of spread of expected income

Based on this rank sum measure the share for each type of participant (farming practitioners/academic scholars) was calculated that *consistently* chose higher risk levels under expectations of good climate than under a stated expectation of bad climate, and/or higher risk levels under a statement of uncertainty about the climate than when stating to expect bad climate, and/or lower risk levels under the statement of a bad climate expectations than under statements of uncertainty about the climate. This was done over ten risk level choices after climate change set in, i.e. for risk level choices between the years six and 15, to exclude the effects of very bad weather outcomes for risk level choices. The following table

(Table 10) depicts the shares of participants in each group that consistently obeyed this criterion. Percentage shares shown in the top row of the table reflect shares of participants from each stratum for whom this analysis could be conducted. These are all participants excluding those who stated either of the three categories consistently throughout the period considered.

Table 10: Consistency in risk level choices over climate expectation statements

Climate Expectations:	**Farmers** *(78.13%)*	**University students** *(81.54%)*
Share of individuals that **always** followed risk level chosen under good climate expectation >indifferent>bad climate expectation	84.00%	77.36%

The comparison shows that obeyance to this criterion was similar in both types of participants. It also can be taken as an indication that the payout mechanism also successfully incentivized - besides crop choices – the expectation statements given and that the observed statements were not independent from risk-level choices in the case of most participants.

4.3.4 Analysis

The observed sequences of statements on which climate was expected show a great deal of heterogeneity among subjects. In order to explain and classify patterns of expectation formation that may underlie participants' responses, these response paths are confronted with sequences of statements predicted by a number of models that incorporate rational patterns of expectation formation as well as different biases and heuristics.

Models of Expectation formation

Rational Expectations

As mentioned before the rationality hypothesis suggests that subjects would use an objectively correct model that incorporates all available information to form their belief about the distribution to be in use. In the given case this means to assume that participants accept equal prior probabilities for favorable and adverse climate before having observed the first draw, and subsequently take into account all weather outcomes at any time to calculate posterior probabilities for each climate, applying Bayes' theorem. Due to different risk preferences, individuals may differ with regard to the posterior probability they take as sufficient to decide for a statement in favor of either one of the two climates. This circumstance can be reflected by defining a threshold posterior probability b, at which the predicted statement of expectation switches between undecided, adverse and favorable climate, allowing a number of different values for b. That means that the ***rational expectations model*** predicts a subject to expect adverse climate if $P(adv|k;n) > b$, to expect favorable climate if $1 - P(adv|k;n) > b$ and to be undecided if $1 - b < P(adv|k;n) < b$. Because variable risk preference with regard to expectation formation is not among the standard assumptions of rational expectation formation, evidence for this mechanism is reported separately from 'standard rational' behavior and referred to as rational expectation formation with elevated risk aversion, or in short expectation formation in line with an elevated ***threshold model***.

One may object that participants were not necessarily able to fully compute posterior probabilities, and as such it would still be rational were they to make use of rule-of-thumb approximations. The simplest approximation to calculating posterior probabilities would be to expect adverse climate in case that more bad than good weather realizations were observed and vice versa. Applying this simple rule-of-thumb in the experiment results in the same sequence of expectations as the rational expectation model with a threshold probability of 55% predicts (similar approximations can be thought of for higher thresholds). Even if participants were not able to exactly calculate posterior probabilities their behavior could still correspond to the predictions of the rational expectations model with different threshold probabilities, if they based their expectation formation on such an unbiased approximation algorithm for the posterior probability.

Biases and heuristics

Despite the obvious random determination of the distribution of balls that represented climate from two options at equal probability, some individuals seem to have assigned a higher probability for one distribution from the outset, as they stated an expectation of either climate before having observed the first draw. Maintaining the assumption of rational probability updating, this can be formally expressed using a biased prior probability in the application of Bayes' theorem. Four ***model specifications with biased prior probabilities*** featuring a prior probability for bad climate to occur $P(adv)$ of 60%, 75%, 40% and 25% are tested in the following, with the last two implying bias in favor of good climate, to reflect pre-set expectation bias of different direction and strength.[35]

Subjects who base their assessment on representativeness and/or availability heuristics would consider only the most recent draws. Formally, such a bias can be expressed using a model that applies Bayes' theorem for making predictions while only taking a small number of recent observations previous to each decision into account. Two ***small sample models*** (in the following also referred to as 'short-sighted models') that consider either the last three or five observations and feature threshold probabilities of b = 55% and 65%, respectively, are applied to reflect this behavior. The models assume indecision before the first draw and expectations based on the threshold probability when less than the stipulated number of observations are available. Depending on the switching thresholds used, this formal model can also be represented by a simple rule: For example, a formal model based on five years and a threshold probability of 55% corresponds to forming expectations based on the majority of weather observations within the last five years. A 65% probability threshold in the five years specification results in predicting the respective climate expectation statement if four or more weather realizations point toward it, otherwise in predicting a statement of ‘unknown’.

Such a recency bias might also be combined with an anchoring heuristic. The corresponding model assumes that individuals start with an initial expectation of either climate and maintain this expectation until two consecutive weather outcomes contradict this expectation. In this case the predicted belief switches to the contrary. Because one weather outcome that contradicts the expectation held is tolerated, this model is referred to as ***tolerance model***. This model features no statement of indecisiveness according to the setup described. Finally, a ***naïve model*** is applied that assumes expectations to be based solely on the previous year's observation. It is implemented as a model that predicts indecisiveness initially and subsequently adjusts predictions according to the weather outcome of the previous year. Table 11 summarizes the models developed and applied to the data.

35 As the possibility to combine different biases is restricted by the structure and amount of data gathered, all of these model specifications assume a threshold probability for switching statements of b = 55% as reflecting a variety of b-values in addition to the different prior probability values would blur the character of the models and result in misleading predictions.

Table 11: Overview of model specifications applied to analyze the experimental data for expectation formation patterns.

Model	Mechanism	Initial prior for adverse climate	Threshold probabilities (b-values) applied
Rational	Bayesian probability updating over all observations	0.5	0.55
Rational with elevated threshold probability (b-value)	Bayesian probability updating over all observations	0.5	0.65, 0.75, 0.85
Biased prior in favor of adverse climate	Bayesian probability updating over all observations	0.6, 0.75	0.55
Biased prior in favor of favorable climate	Bayesian probability updating over all observations	0.4, 0.25	0.55
Small sample	Bayesian probability updating over last 3 or 5 years	0.5	0.55, 0.65
Tolerance	Change after two subsequent weather observations contradict an established expectation	0, 1	-
Naïve	Statement equal to weather outcome of previous year	0.5	-

4.4 Results

4.4.1 Model selection results

Model fits

To compare the sequences of statements predicted by the different model specifications with the sequences of statements retrieved from participants a goodness-of-fit measure (GoF) is derived by calculating the percentage of statements of a participant that were correctly predicted by each of the respective model specifications. In order to relate empirical findings from the experiment to frequently encountered representations of patterns of expectation formation in economic models, the ***rational model*** featuring a threshold probability of b = 55% is used as benchmark. Subjects' following this objective and rational mechanism of expectation formation is used as null-hypothesis in the model assignment procedures introduced in the following.

4.4.2 Models assigned according to the basic assignment procedure

The basic criterion for a rational model to be considered valid to describe the observed expectation formation of a given subject is the achievement of a goodness-of-fit of at least 66.67% of the observed statements, which corresponds to 10 out of 15 expectation statements correctly predicted. If no alternative model reaches this threshold, or if an alternative model explains the observed sequence merely equally well, we stipulate that rational expectation formation cannot be refused to apply for this subject. Applying the principle of conservativeness, this assumption is maintained if an alternative model specification fits better than the rational standard model but at less than 13.33%, which corresponds to less than two statements predicted better than the rational benchmark model does.

Following this procedure, a subject is only categorized to employ one of the alternative mechanisms of expectation formation formalized in one of the non-rational models, if (i) the alternative model predicts the observed sequence of statements to more than 66.67% and the benchmark model does not do so, or (ii) if the rational model predicts the observed sequence of statements to more than two-thirds but the alternative model specification predicts two or more than two of the observed statements in addition to the rational model correctly. This at least 'two-predictions-difference-rule' is applied as well in cases when alternative models fit the data best. In cases in which this criterion is not fulfilled the subject is listed as 'ambiguously' assigned to follow one of the alternative modes of expectation formation. However, in cases that all of the tested models predict less than 10 out of 15 statements correctly, it can only be derived that (i) the subject did not employ a rational mechanism when building expectations about the underlying climate, and (ii) that none of the expected heuristics and biases were applied, at least not in line with the considered magnitudes or not consistently. In these cases, subjects' expectation formation is considered 'unexplained'. The following table (Table 12) lists the mechanisms that were found, the classes of bias they belong to as well as their distribution in the full sample.

Table 12: Assigned mechanisms of expectation formation and respective shares of participants

Total subjects:	*Rational mechanism (32 Obs./32.99%)*		*Risk aversion (5 Obs./5.15%)*	*Pre-set expectation bias (22 Obs./22.68%)*	
97	Unambiguously rational	Rational expectation formation cannot be refused	Rational expectation formation with risk aversion	Rational expectation formation with bias in favor of bad climate	Rational expectation formation with bias in favor of good climate
Frequency	8	24	5	18	4
Share	8,25%	24,74%	5,15%	18,56%	4,12%
	Myopic Mechanisms (6 Obs./6.19%)			*Not explained (32 Obs./32.99%)*	
	Myopic rational/rational elevated	Myopic/anchoring	Myopic/absence of learning		
	Rational expectation formation with short time horizon	Tolerance	Naïve mechanism of expectation formation	Ambiguous between alternative mechanisms	No model fits data > 66.66%
Frequency	1	3	2	10	22
Share	1,03%	3,09%	2,06%	10,31%	22,68%

As the table shows, expectation formation following the assumptions of a standard rational mechanism cannot be refused for about one third of the participants (32 subjects, or 32.99%), at least not on cautious grounds. For about two-thirds (67.01%, or 65 subjects) however, expectation formation in the experiment that followed a standard rational mechanism is refused, based on the described assignment procedure.

4.4.3 Models assigned after clearing for end-effects

The analysis presented above takes the full range of observations when climate is uncertain into account, i.e. it is based on a sequence of 15 statements of climate expectation per participant. Evaluation of the data structure based on individual sequences however, yielded hints for the presence of likely end-effects during the last period, i.e. during year 20. The effect is of the kind that individual risk level choices strongly increased with the last cropping decision in some cases, even if counter intuitive regarding the signals implied with the observed sequences and often outside usual magnitudes. This observation was taken as a hint that some of the participants resorted to gambling towards the end, probably treating the last round as a one-shot lottery rather than in the sense of maximizing total final wealth in a sequence of decision.

To avoid biasing the empirical results with this suspected effect, a second assignment procedure was applied to the data that excluded all observations for the year 20 from the analysis. This removal of one observation from all sequences implied that the threshold for acceptance of a model increased to 71.43%, which corresponds to ten out of 14 observed statements correctly predicted by the respective model specification. However, the two-observations-difference rule for refusing the benchmark model of standard-rational behavior and for distinguishing between alternative models of expectation formation was maintained in this procedure. Doing so caused a loss in discriminatory power of the analysis procedure, ten more participants are now assigned to employ an unexplained mechanism of expectation formation, increasing this share from about 33% to 41.2%, as depicted in the following table (Table 13).

The general tendency of the findings maintains the same nevertheless, as about 30% of the participants are identified to employ a mechanism of expectation formation that is sufficiently well explained with rational expectation formation, and no other of the specified mechanisms of expectation formation performs (based on the assignment procedure described) significantly better. This share consists of 9.3% of participants for whom the rational expectation model performed best in predicting expectation statements and 20.6% for whom rational expectation formation could not be refused. Rational expectation formation in combination with risk aversion was found to account for 4.1% of the participants, while 15.6% employed rational mechanisms of expectation formation characterized by a pre-set bias in favor of either climate, 14.45% in favor of adverse climate, and 5.2% in favor of expecting advantageous climate.

Table 13: Assigned mechanisms of expectation formation and respective shares of participants after cleaning for end-effects

Total subjects: 97	*Rational mechanism (29 Obs; 29.90%)*		*Risk aversion (4 Obs; 4.12%)*	*Pre-set expectation bias (19 Obs; 15.59%)*	
	Unambiguously rational	Rational expectation formation cannot be refused	Rational expectation formation with risk aversion	Rational expectation formation with bias in favor of bad climate	Rational expectation formation with bias in favor of good climate
Frequency	9	20	4	14	5
Share	9,28%	20,62%	4,12%	14,43%	5,15%
	Myopic Mechansims (4 Obs; 5.15%)			*Not explained (40 Obs; 41.24%)*	
	Myopic rational/ rational elevated	Myopic with anchoring	Myopic/absence of learning		
	Rational expectation formation with short time horizon	Tolerance	Naïve mechanism of expectation formation	Ambiguous among alternative mechanisms	No model fits data > 71.43%
Frequency	1	3	1	8	32
Share	1,03%	3,09%	1,03%	8,25%	32,99%

Myopic rational and myopic rational mechanisms with an elevated threshold (short: ‘rational elevated’) as represented by the small sample model, was found to account for 1% of participants, which corresponds to one subject. Naïve expectation formation was found to occur with the same relative frequency in the sample (1%), while roughly 3.1% of the participants were assigned having followed a myopic mechanism with anchoring heuristic, as represented by the tolerance model. 8.25% of observed patterns of expectation formation could merely be ambiguously assigned to employ an alternative mechanism of expectation formation, as several of the tested alternative models fitted the data similarly well, and 33% of participants could not be explained, neither with the rational model, nor with any of the variants assuming alternative expectation formation behavior, together accounting for the 41.2% of unexplained mechanisms overall.

4.4.4 Determinants of heterogeneity

In a last step, expectation formation was analyzed based on groups of participants. The following table (Table 14) presents a listing of shares identified for the respective expectation mechanisms disaggregated by the two participant groups, farming practitioners and agricultural scholars with academic background. Considerable heterogeneity in expectation formation was found between the two groups of participants: Expectation formation in line with a standard rational model of expectation formation was the most frequently encountered pattern in the group of academic agricultural scholars, featuring a share of 33.85% among them, while it accounted for a share of 21.88% of farmer participants (or, at least could not be refused to account, based on the stipulated criteria).

With a share of 6.25% among farmers, rational expectation in combination with risk aversion was more than twice abundant as in the group of academics (3.08%), in relative terms. A rational mechanism of expectation formation biased towards a bad climate was found to be the second-most employed mechanism of expectation formation that could be unambiguously identified in academic experts, while it accounted for 9.38% of farming practitioners according to the applied procedure. Surprisingly, this share was equal to the share of non-academic agricultural experts that applied rational expectation formation in combination with a bias towards good climate and could be identified by means of the model assignment procedure, while this type of bias was found to only play a role for the expectation formation in 3.08 of academic participants. A closer look into the data subsequent to conduction of the formal procedure revealed however, that three more individuals from the sub-group of experienced farmers – which corresponds to a share of 20% from this sub-group of practitioners – that are listed under ‘unexplained expectations’ according to the formal procedure, in fact made statements throughout the experiment that can be explained with an 'extreme' bias in favor of good climate, i.e. with threshold probabilities for good climate outside the range accounted for in the tested models. This feature nevertheless was only observed for bias in favor of good climate and only for the case of elder, i.e. experienced farmers. This makes rational expectation formation in combination with a bias in favor of good climate the second-most prevalent mechanism of expectation formation identified in farming practitioners that participated in the experimental sessions and was found to account for 6 out of the 32 (18.75%) individuals in total, from this group of participants.

Table 14: Assigned mechanisms by participants status after cleaning for end-effects

	Rational mechanism		*Risk aversion*	*Pre-set expectation bias*	
	Unambiguously rational	Rational expectation formation cannot be refused	Rational with risk aversion	Rational & bias toward bad climate	Rational & bias toward good climate
Farmers	21.88%		6.25%	9.38%	9.38%
University students	33.85%		3.08%	16.92%	3.08%
	Myopic Mechansims			*not explained*	
	Myopic rational/ Rational elevated	Myopic with anchoring	Myopic/absence of learning		
	Small sample	Tolerance	Naive mechanism	Ambiguous	No model fits data > 71.43%
Farmers	-	6.25%	3.13%	-	43.75%
University students	1.54%	1.54%	-	12.31%	27.69%

Prevalence of the remaining expectation patterns small sample bias, tolerance and naïve expectation formation was found to be low in both groups, except for the case of myopic expectation formation with anchoring bias (represented by the ‘tolerance’-model), which was found to account for 6.25% of farmer participants. Small sample bias was absent in the group of faming practitioners while naïve expectation formation could not be detected to be a mechanism of expectation formation present in the academic agricultural scholars. Ambiguous expectation formation that could be explained by inconsistent use of expectation rules was found to apply for 12.31% of University students while this feature was not present in the group of farming practitioners. Expectation statements of significant shares of individuals from both groups – 43.75% of farmer participants and 27.69% of the participants with academic background – could not sufficiently well be explained by any of the models tested.

4.4.5 Determinants of expectation formation

Tests for association of categories

For detecting influencing factors for the identified expectation formation patterns, a number of statistical tests were conducted. To test for an association between categorical variables in r x c contingency tables with small count numbers, an exact test based on hypergeometric probability and a network algorithm is required (Mehta & Patel, 1983). Fisher's exact test implemented in STATA fulfils these requirements and has been applied to the data, testing for independence between participants' status (based on the three categories experienced farmer, young farming practitioner and academic) and expectation mechanism assigned. Based on this test, the hypothesis of independence between these two characteristics is refused, at a 5% level of significance[36]. The stratified sample required a Cochran-Mantel-Haenszel-test to test for independence between expectation formation patterns observed and sequence received (i.e. the 'climate' observed by participants). The null hypothesis of independence between these two variables was rejected at a 10% level, based on this test[37]. A Mantel-Haenszel χ^2-test was conducted applying two different formulations for age-categories to test for an association of age and patterns of expectation formation and to account for the ordinal categorical data. This test delivered no hints for an association between the variables age and expectation formation for neither of the two specifications of the age category, however[38].

4.5 Discussion and conclusions on the experimental approach

Limitations and generalizability

The experimental approach to research patterns of expectation formation in the context of agricultural decision making and climate change delivers hints that these patterns are highly diverse among individuals engaged in the field of agriculture. Apart from differences in patterns of expectation formation rooted in the profession, specialization, personal experiences, age and worldviews of individuals in general, or with regard to the context of climate change related judgments in particular, trust in the experimental procedure and a tendency to show rational patterns of behavior might as well be influenced by a participant's familiarity with abstract representations of a problem and his or her understanding of stochasticity

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36 See Appendix section C3.1 for results of the statistical testing procedure.

37 See Appendix section C3.2 for results of the statistical testing procedure.

38 See Appendix section C3.3.1 and C3.3.2 for results of the statistical testing procedures.

and random realizations of outcomes, features that are related to the training an individual received.

Further, it is conceivable that the initial expectations stated by the participants might be influenced by (i) real world experience with current climate conditions, (ii) their actual belief on the direction of the effects of climate change in their region, or (iii) by an expectation on the intention of the institution or the experimenter conducting the research. In order to minimize these effects, a highly transparent experimental procedure was ensured. Smith (1976) and Hey (1994) emphasize that in addition to this, with regard to the external validity of experimental approaches, it is essential to motivate participants with monetary payouts to ensure behavior during the experiment that corresponds to real-life behavior in economic decision contexts. Although statements on expectations about the climate in effect were not directly rewarded, the motivation to earn money from crop production to be a sufficient incentive to make an informed and realistic guess on the actual climate can be expected, based on the analysis of consistency between stated climate expectations and risk level choices. On the contrary, rewarding correct guesses might have induced bias, as statements of indecisiveness would have been dis-incentivized.

While the random procedures involved in the experiment proved necessary in order to assure trust, and due to the ease of demonstrating independence compose one of the beauties of the experimental design, they also generate problems. The random climate selection procedure as well as the determination of weather outcomes based on random draws pose problems for the experimenters: Resulting sequenced (and total monetary payments as well) are only predictable to a limited extent. As a result, several experimental sessions with sufficiently large groups of participants might be required to generate sufficient variability in results and to establish generalizable results. Repeating treatments which have previously been randomly determined and communicating this in a trustful way to participants has proven to be a remedy for the problem of too small sample sizes for one treatment.

Conclusions

A payout-motivated economic experiment was used to observe individual decision making under risk induced by climate change and to examine how expectations about altered climatic conditions are formed. To do so, weather outcomes during the experiment and dependent climate expectations of participants were observed. The experimental framework provides a way to “re-translate” statistically described information about the nature of climate change into experiential information and the sequential nature of the decision task as well as the iterative character of learning induce a high degree of relatedness to the real-world characteristics of climate change. It thus incorporates decision structures and learning trajectories and addresses mental processes that are highly relevant for decision making and taking actions, especially in the context of dealing with climate change outcomes. At the same time, the experimental design and implementation proved to be straightforward and easy to grasp as well for non-academics and people not used to working with computers.

The findings underscore the importance of considering heterogeneity in expectation formation mechanisms, the rate of incorporation of information, and related individual-specific valuation of climate and weather information. These are scientific questions of high relevance for policy makers, extension agents and communication experts concerned with climate change issues. Results were achieved using fictional probability distributions concerning the direction of climate change and were connected to hypothetical outcomes for crop profitability in the short to medium term. Provided the availability of probabilistic information on the direction of climate change in a certain region, the experimental design could be used to research behavior under predicted probability distributions for future climatic conditions and related changes in behavior could be measured.

For further theory development or even a quantitative estimate of the prevalence of different expectation formation patterns and relevant biases, the experiment will need to be repeated on a larger scale, with more participants and a greater variety of weather-time series. Estimates from these experiments can then be implemented in agent-based simulation models to assess farmer climate adaptation and suitable policy interventions (Berger & Troost, 2014). In addition, more experiments will also allow for establishing robust statistical relationships between demographic characteristics, learning-related variables, such as the individual-specific value of weather information, and their influence on expectation formation. Ultimately, this could help clarifying whether increased training in dealing with statistical information could increase the degree of rationality involved with forming expectations on climatic change.

5 Discussion

The final chapter of this thesis discusses implications of the empirical findings for Agent-based modeling approaches applied to agricultural adaptation assessment and derives recommendations on how the empirical findings could be used to inform more realistic representations of human decision making in the context of climate change response of the agricultural sector. A last section refers to further research needs and recommendations for future research.

5.1 Recommendations for agricultural land use climate adaptation modeling with MPMAS

Empirical research conducted within this study brought up an array of indications for real-world decision making in the context of agricultural adaptation to climate change that is not captured by the model of the rational human actor (*homo oeconomicus*). Central to the concept are - in a narrow sense - the assumptions of perfect knowledge of the actor (i.e. full foresight at no cost), stable preferences, maximization of an individual utility function through optimal decisions based on unbiased (and unlimited) calculations and the notion of utility to be based on the principle of selfishness. The empirical findings presented however point toward (i) heterogeneity in the perception and awareness of signals for climatic changes and expected consequences, (ii) impacts of personal experiences and circumstances, cognitive limitations and the social environment for the evaluation of signals significant for adaptation decisions such as the perception of climate and weather related risks, and for (iii) a selective assessment of potential adaptation options influenced by mental models about climate change and its effects, potentially in combination with risk aversion, and (iv) the widespread presence of heuristics and biases in climate change related expectation formation.

The MPMAS simulation modeling software allows to account for heterogeneous and non-rational aspects of human decision making in a number of ways:

Social norms, personal goals and heuristics: The effects of social norms, personal goals or other aspects of human behavior (such as risk avoidance) can be modeled via translating the underlying behavioral rules into constraints that determine agent behavior through the solving process that underlies the model, i.e. constraint optimization (Berger & Troost, 2014; Schreinemachers & Berger, 2006).

Agent heterogeneity: Typically heterogeneous agent characteristics such as biophysical and socioeconomic conditions as for instance, various soil types, crop and vegetation growth, land holdings, social networks and human actors is accounted for by extracting probability functions from socioeconomic surveys and assigning the respective characteristics to the model agents via Monte Carlo techniques. Through this process landscapes and agent populations can be created that are statistically consistent with empirical observations (Berger & Schreinemachers, 2006).

Learning: Learning and adoption of new technologies (for instance adaptation measures) is implemented via a threshold mechanism for innovation diffusion which defines thresholds for innovativeness for agents and by connecting these thresholds to the proportion of peers that already adopted the innovation (Berger, 2001; Schreinemachers et al., 2009).

Incomplete access to information, information diffusion and social knowledge: Dynamics in information diffusion and differences in access to information can be represented via communication networks that connect different sub-populations of agents, with or without information spillovers and by attributing changing weights to external information (Berger, 2001).

Expectation formation: Expectation formation is explicitly implemented for expectations about prices and yields and assumes some sort of adaptive expectation formation to reflect the fact that real-world decision makers usually cannot predict these decision parameters with certainty (Schreinemachers & Berger, 2011).

In the light of the presented empirical studies however, a number of extensions to the representation of agents' decision making can be derived, that potentially improve validity, traceability and robustness of simulation modeling results. The recommendations follow the conceptual model of perception and adaptation based on Nguyen et al. (2016), presented in the introduction of this thesis (Section 1.2).

5.1.1 Explicit representation of signal interpretation and climate expectations

Reception of signals

The Likert-scale questions presented in Chapter 2 found that a majority of farmers in the two research regions observed a change in typical local weather conditions. In addition, both the perceived risk assessment and social representation study, as well as the mental models about adaptation options (Chapter 3) imply, that farmers receive signal from the biophysical environment and interpret them in terms of climate change, and likely also in terms of climate change related risks. The findings point toward perceptions and understandings of climate change in terms of an increased weather variability, an increased incidence of extreme weather events and of a general warming, which is in line with the predictions based on scientific data.

Interpretation of signals

Personal characteristics and characteristics of the farm-business were found to influence the perception of local weather changes and expectations about their farm-level effects presented in Chapter 2. Those characteristics were: respondents’ age, location of the farm, share of agricultural income and farm profit for the perception of changes in local weather conditions. Farmers' age, location of the farm, method of production and farm size were significant predictors for expectations about consequences, with farmers from the Kraichau perceiving more often that the changes were to the disadvantage of their farms, with the variables age and profit being negatively related with this perception (Table 4). In both regions, climate and weather-related risks were the farm-level risks most often perceived, with a larger share of farmers from Kraichgau that connected this kind of risk to concrete weather outcomes in their statements, as depicted in Figure 6. Findings indicate however that the perception of climate risk (and, potentially, one step before, the perception of climate signals) might be reduced by the presence of other perceived risks, such as health- and other personal risks or, in the light of recent developments in other fields that are source to alternative significant perceived risks (Table 5). This might affect the willingness to adapt to climate change, as perceived risks are found to be among the major drivers for adaptive response (Grothmann & Patt, 2005).

Accounting for biophysical and socioeconomic signals in modeling

From these findings, a range of conclusions for agent-based models can be derived: (i) interpretation of signals is influenced by heterogeneous agent conditions that probably relate to the magnitude and direction of the observed effect, stakes involved and perceived vulnerability, (ii) to socio-demographic factors (age, life-cycle stage), and (iii) a finite pool of worry related to limited processing capacity of individuals. These factors might interrelate with expectation formation and probably adaptive response. The effects these factors have could be summarized via a posterior probability function (similar to the one described in the experimental section) that reflects climate change awareness and influences the readiness to react. It is therefore recommended to account for the type of signals received from the environment and for the way they are interpreted, by explicitly modeling expectation formation about climate change and by accounting for factors relevant for signal interpretation. Those suggested factors are:

Personal factors: Socioeconomic factors could be distributed according to the results from the socioeconomic survey for the samples of the two regions.

Interpreting climate signals: The way how posterior probabilities about climate change expectations are formed in individuals could be informed by findings from the experimental approach, indicating an influence of participant status (related to formal education and experience in the field) and of the nature of the sequence of climate signals.

Extreme events and drastic experiences: Extreme experiences e.g. related to financial losses of a great magnitude or other adverse experiences (e.g. loss of an entire yield or life stock) can disproportionately influence risk perception and the readiness to react to a signal, even if compensated. This effect on climate change awareness could be informed by the outcomes of the atmosphere-land surface-crop model (ALCM) or via the simulated farm level effects in FarmActor.

Social interactions: The effects of social interaction for climate change awareness could be represented by the social networks feature and through interactions of famers in groups that share similar norms and worldviews, e.g. defined by farming styles (Eggers, Kayser, & Isselstein, 2015; Hyland, Jones, Parkhill, Barnes, & Williams, 2016) or production method (e.g. ecologic vs. conventional production).

Finite worry: The source of competing risk perceptions could be modeled input prices, output price (expectations), outcomes of simulated socioeconomic processes (e.g. policy making or local land markets) and, as a proxy for personal risks, life-cycle stage or household income.

5.1.2 Accounting for subjective perception of adaptive capacity

Conceptualizations of farm-level adaptation

Findings on mental models about adaptive capacity suggest that conceptualizations of adaptation options are influenced by (i) the perception of climate related risks, (ii) personal factors such as age of the farmer in the Central Swabian Jura, and likely (iii) expectations about the existence and direction of effects of climate change and the perceived ability to counteract the perceived changes, in combination with a widespread tendency to cite short-term changes that don't come along with large investments and that are revocable. This can be interpreted as an indicator for risk aversion and the effect of uncertainty involved regarding the long-term effects of the climate signals observed and interpreted.

Reflection of heterogeneity in adaptive behavior

The process of constraining the range of decision alternatives has been discussed in Schreinemachers & Berger (2006). In this sense, sets of activities could be made available to the agents to reflect findings from the empirical surveys, such as:

Influence of climate change expectations: Adaptation knowledge should be tied to expectations about climate change and through that with factors such as, for instance, the experience of high stakes events and resulting risk perceptions. Stating knowledge about perceived adaptation options was statistically significantly related to the circumstance if farmers in the sample had perceived climate related risks. A higher posterior probability for climate change with negative farm level effects modeled in the previously suggested explicit representation of climate change expectations could increase the willingness to take risks related to adaptation measures and to select activities that would not be selected otherwise. This could be reflected by a (temporarily) increased set of adaptation options made available to agents if posterior probability for negative climate effects is high, e.g. in the aftermath of experiences of extreme weather events.

Preference for short-term adaptation: In order to circumvent the risk of financial losses related to maladaptation, a preference for short-term adaptation could be reflected by the sub-sets of adaptation measures agents can choose from. To reflect real-world practices, agents could also be enabled to 'practice' a certain technology or new production activity on a small scale in order to reflect coping with uncertainty and divisibility of adaptation options.

Application of heuristics, e.g. of **routines in crop choice** or certain field tasks. It can be assumed that adaptation is not a continuous process but rather a process characterized by sudden jumps, triggered by interrupting experiences. This might be due to the fact that learning often occurs in case of unusual experiences (often related to losses) that trigger deliberate thinking about behavior. This effect could be captured by implementation of a habitual/reinforcement learning algorithm which assumes that unsatisfying experiences (e.g. yields that do not meet a certain target) trigger deliberate thinking and new (adapted) behavior. Learning could be implemented as well heterogeneously and, (at least in parts of the agent population) as reinforcement learning, which would consider a certain level of hysteresis and behavior based on heuristics. This would likely reflect some of the behaviors implied by the remarks to non-responses (e.g. "not thought about adaptation measures yet" or of adaptation being a problem of "minor relevance" at the moment).

Influence of life-cycle stage: Empirical findings based on t-tests indicated a significantly lower average age for Central Swabian Jura farmers that expressed knowledge about adaptation options. This could be taken as an indicator that the willingness to think about adaptation options and to implement them decreases with the life-cycle stage of a farmer. Moreover, willingness to adopt activities that require major investments or significant changes in farm organization can reasonably be expected to decrease for farmers in a late life-cycle stage, if no farm successor is available. It can therefore be recommended that adaptation activities made available to agents could be connected to the life-cycle and farm-succession feature of MPMAS (Troost & Berger, 2016).

5.1.3 Informing modes of expectation formation by experimental findings

The experimental findings suggest that a number of biases and heuristics exist at the individual level that affect patterns of expectation formation. These findings could be extrapolated and applied to the expectation mechanisms implemented for price and yield expectations, e.g. by reflecting differences in the degree of rationality of expectation formation that vary with agent characteristics and the strength and markedness of the signals received.

5.2 Recommendations for further research

The presented findings would allow for a greater degree of complexity in the representation of human behavior in agent-based models and allow for reflecting the effects of agent- and location heterogeneity and thus individual- and location specificity of certain reactions to climate change more explicitly, as requested by Berger & Troost (2014). Nevertheless, they are mainly based on indicative findings for which statistically significant relationships could only partly be established and representativity of the socioeconomic variables could not be ensured. This implies the following recommendations for further research.

5.2.1 Survey approaches

More formalized survey questions that build upon the indicative findings of the presented studies should be implemented to complement the indicative findings and trends of a qualitative character. Optimally, representative longitudinal studies of panels of respondents would be used to assess which of the revealed characteristics are stable in the time as well as in a personal dimension and which processes influence potential dynamics. Another subject to research could be which kind of signals and farm level outcome are connected to which kind of biases (e.g. recency bias, competing risk effects, etc.) and which social factors lead to which results in climate change perception and expectations about effects. The effects of psychological proximity to perceived climate change outcomes should be further researched as well. Currently a third survey is implemented that revisits the sample of farmers that participated in the 2010 farm survey, with the purpose (among others) to draw conclusions on time stability of experiences with and interpretation of climate signals, as well as on the role of learning from peer observations for adaptation choices.

5.2.2 Suggestions for improvements of the experimental approach

Avoiding end-effects

Gambling towards the end of the experiment could be avoided by not telling for how many rounds the experiment will last.

Measurement of expectations via subjective probabilities instead of categorical statements

A measurement of subjective probabilities to represent the respective climate expectation would further refine the conclusions that can be drawn with regard to individual expectation formation patterns, as this would offer a greater resolution with regard of the interplay between the observed evidence for an uncertain outcome (i.e. the actual climate in force) and the translation into expectations/subjective probabilities. Further, assessment of expectations in terms of subjective probabilities would comply with the subjective expected utility (SEU) framework and simplify the analysis of expectation statements and simultaneous risk level choices.

Prolonging the experimental procedure

One of the main shortcomings of the presented approach was found to be that the amount of observations per individual under the same experimental conditions (uncertain climate) is relatively small, which restricted the precision of the inferred conclusions about expectation formation patterns. A prolongation of the experimental procedure to 20 to 30 periods under unchanged conditions of uncertain climate while recording expectations is therefore recommendable.

Repeated conduction with the same individuals

This would allow for (i) a better statistical analyzability of data due to more observations per subject (ii) checks for the stability of patterns of expectation formation and risk taking behavior on the basis of the individual and with regard to the nature of the received random sequences, and iii) researching the impact of variations in the decision context.

Increase sample size per stratum

In order to draw more reliable conclusions about differences in expectation formation behavior due to occupation (and on the related questions for impacts of field-experience and formal education for the information processing modes), an increase of the sample sizes per stratum of participants in combination with ensuring representativity with regard to the respective populations would likely be fruitful.

5.2.3 Conduction of simulation experiments based on the empirical results

As a first step, the suggested implementations of further behavioral aspects in the context of climate change could be tested in test simulation runs, based on the empirical findings presented in this study. For example, the potential impacts of sudden changes of mental models in case of a changed social discourse in favor of/against the occurrence of serious consequences of manmade global climate change could be studied in this case. Also, the effects of a sudden reduction of the uncertainty that surrounds the prediction of climate change impacts at the regional scale could be simulated, both with regard to short- and long-term uncertainty (e.g. by assuming improved seasonal versus long-term regional climate condition forecasts that feature a fine resolution and a high level of confidence). Also, the perceptional effects of different possible trajectories of climate change could be investigated, for instance by simulating trajectories characterized by a high number of extreme events versus ones that feature relatively small increases in the variation of weather conditions that gradually evolve over a relatively long period of time.

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Appendix

A Weather Statements

A1 Multiple regression results weather statements

	Model 1	Model 2	Model 3	Model 4
region	0.685***	0.427*	0.607**	-0.773**
	(2.99)	(1.79)	(2.23)	(-2.62)
age	-0.156**	-0.0188	-0.0285**	0.0463***
	(-2.08)	(-1.57)	(-2.13)	(2.96)
sq_age	0.00139*			
	(1.88)			
profit	-0.0266**	-0.0288***	-0.0155	
	(-2.55)	(-2.66)	(-1.28)	
sq_profit	0.000167***	0.000197***	0.000111	
	(2.91)	(3.32)	(1.64)	
inc_agr	0.0151***	0.0112**	0.000316	-0.00766
	(3.20)	(2.29)	(0.06)	(-1.49)
area_sum	-0.00390	-0.00469	-0.00342	0.00758**
	(-1.32)	(-1.51)	(-0.96)	(2.17)
mgm	0.606	0.922**	0.00547	-0.967**
	(1.59)	(2.40)	(0.01)	(-2.06)
h_profit				-0.000000257
				(-1.45)
_cons	8.100****	5.273****	5.162****	1.184
	(4.31)	(8.30)	(7.23)	(1.42)
N	130	133	117	114
R^2	0.200	0.164	0.119	0.180
p	0.000537	0.00180	0.0484	0.00142

t statistics in parentheses
* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$, **** $p < 0.001$

Source: Article's main author, Aileen Jänecke, Gießen.

B Survey Documentation

B1 Word associations

B1.1 Survey Questions

Original survey question word associations:

Was kommt Ihnen zuerst in den Sinn, wenn Sie an Klimawandel denken? *Notieren Sie bitte stichwortartig...*

B1.2.1 Categories of word associations applied to farmer school student data

code	text	count	share of respondents
1	weather extremes	25	48,1%
2	global warming	9	17,3%
3	climate warming	11	21,2%
4	warmer	11	21,2%
5	abrupt weather changes	4	7,7%
6	increase of heat days	5	9,6%
7	more drought periods	5	9,6%
8	milder winters	6	11,5%
9	heavy rains	6	11,5%
10	more precipitation	4	7,7%
11	less precipitation	3	5,8%
12	agricultural practice	6	11,5%
13	ozone (hole)	4	7,7%
14	heavy weathers	5	9,6%
15	cold extremes	3	5,8%
16	ice melt	4	7,7%

Source: own documentation.

B1.2.2 List of word associations farmer school students

Statement	Category
extrem Wettersituationen	1
Extreme Wetterbedingungen (Starkregen, Hagel, Trockenheit, kein Frost im Winter)	1
extreme Wettererscheinungen	1
extreme Wetterlagen	1
extreme Wetterlagen	1
extreme Wettersituationen (Trockenheit/Nässe)	1
extreme Wetterumschwünge;	1
Extremwetterlagen	1
Extremwetterlagen -> Ernteausfälle, - verluste	1
häufigere Wetterextreme	1
mehr Wetterextreme	1
stärkere Wetter/Temperatrschwankngen	1
stärkere Wetterextreme	1
steigende Wetterextreme	1
Wetterextreme	1
Wetterextreme	1
Wetterextreme	1
Wetterextreme	1
Wetterextreme	1
Wetterextreme	1
Wetterextreme (Dürreperioden, Niederschlagsexplosionen)	1
Wetterextreme (starke Hitze, stärkere unwetter)	1
Wetterextreme (Trockenheit, Starkregen, Gewitter,…)	1
Wetterextremen	1
Zunahme von Wetterextremen	1
Erderwärmung	2
Erderwärmung	2
Erderwärmung	2
Erderwärmung	2
Erderwärmung	2
Erderwärmung	2

Erderwärmung	2
Erderwärmung	2
Temperaturanstieg auf der Welt	2
Klimaerwärmung	3
Klimaerwärmung	3
Klimaerwärmung	3
Klimaerwärmung	3
Klimaerwärmung	3
Klimaerwärmung	3
Klimaerwärmung	3
Klimaerwärmung	3
Klimaerwärmung	3
Klimawandel (erwärmung)	3
Klimawerwärmung	3
Durschnittstemperatur steigt	4
Erwärmung	4
es wird wärmer	4
hoher Durschnittstemp.	4
höhere Durschn. Temperaturen	4
sehr leichte Erhöhung der Durschnittstemperatur	4
steigende Temperaturen	4
Warm	4
Wärmer	4
Wärmer	4
wird wärmer	4
die extreme Wetterumstellung	5
Wetterkapriolen	5
Wetterumschwung	5
Wetterveränderungen extrem Schnell	5
heftige Sommer	6
heiße Sommer	6
Hitze	6
Hitzetage nehmen zu	6
Hitzetage nehmen zu	6

Trockenheiten	7
Trockenheiten	7
Trockenphasen in Zukunft	7
Vorsommertrockenheit	7
wird trockener	7
milde Winter	8
milde Winter	8
milde Winter	8
milder Winter	8
milder Winter und im Jahr zuvor extrem lange und kalt	8
z.T. aber auch milde Winter	8
hohe Niederschlagsmenge aufeinmal	9
starke Regenfälle	9
Starkregen	9
Starkregen	9
evt. Viel Regen auf einmal	9
Überschwämmungen	9
Nässer	10
in der Ernte mehr Regen	10
mehr Niederschlag	10
mehr Regen	10
weniger Niederschlag	11
weniger Niederschlag	11
weniger Regen im Sommer	11
Anbau von anderen Kulturen	12
knappere Erntefenster (Zeitdruck)	12
neue Anbaukulturen	12
Persönliche Risiken	12
Produktionsschwierigkeiten	12
Risiken für den Anbau landwirtschaftlicher Kulturpflanzen	12
Ozon	13
Ozonloch	13
Ozonloch vergrößert sich	13
Ozonschicht	13

Unwetter	14
Unwetter nehmen zu	14
Hagel	14
mehr Naturkatastrophen	14
Sturm	14
Kälte	15
Kältextreme	15
z.T. sehr lange u. kalte Winter	15
Eisschmelze	16
Pole schmelzen	16
Schmelzen der Glätscher	16
schmelzendes Eis	16

Source: own dataset.

B1.3.1 Categories of word associations applied to student data

code	keyword	count	Share %
1	biodiversity	11	6,79
2	sea-levels	7	4,32
3	Co2	16	9,88
4	global warming	20	12,35
5	ice melt	27	16,67
6	warmer	7	4,32
7	weather extremes	11	6,79
8	climate warming	5	3,09
9	environmental pollution	5	3,09
10	ozone (hole)	7	4,32
12	droughts	3	1,85
14	animal husbandry	7	4,32
17	catastrophe	9	5,56
22	energy production	8	4,94
20	weather changes	6	3,70
23	human cause	13	8,02

Source: own documentation.

B1.3.2 List of word associations undergraduate students

Statement	Category
Artensterben	1
Artenvielfalt	1
aussterbende Tierarten im Meer	1
Bedrohung v. Tierarten (Eisbär...)	1
Eisbären	1
Eisbären	1
Eisbären	1
Eisbären	1
Abnahme der Biodiversität	1
Pflanzensterben und Tiersterben	1
Tiersterben	1

ansteigender Meeresspiegel	2
Anstieg des Meeresspiegels	2
Anstieg des Meeresspiegels	2
Anstieg des Meeresspiegels	2
steigender Meeresspiegel	2
steigender Wasserspiegel	2
Erhöhung des Meeresspiegels	2
CO2	3
CO2	3
CO2	3
Co2	3
Co2	3
Co2	3
CO2	3
CO2	3
Co2 + methan	3
CO2 Ausstoß	3
Co2 Austoß	3
CO2-Ausstoß	3
Erhöhte CO2-Konzentration	3
Treibhausgase	3
Treibhausgase	3
Treibhausgase, Co2	3
Erderwärmung	4
Erderwärmung	4
Erderwärmung	4
Erderwärmung	4
Erderwärmung	4
erderwärmung	4
Erderwärmung	4
Erderwärmung	4
Erderwärmung	4
Erderwärmung	4
Erderwärmung	4

Erderwärmung	4
Erderwärmung	4
Erderwärmung	4
Erwärmung der Erde	4
globale Erwärmung	4
Globale Erwärmung	4
Globale Erwärmung	4
Globale Erwärmung	4
Globale Erwärmung	4
Eis	5
Eis schmilzt	5
Eis-/Gletscherschmelze	5
Erderwärmung und deren Folgen (Gletscherschmelze usw.)	5
Gletscher	5
Gletscher schmelzen	5
Gletscherschmelze	5
Gletscherschmelze	5
Gletscherschmelze	5
Gletscherschmelzen	5
Gletscherschmerlze	5
Pole	5
Pole schmelzen etc.	5
Politik schläft	5
Polkappen	5
Polkappen	5
polkappenschmelze	5
Schmelzen der Pole	5
Schmelzen der Pole	5
Schmelzen der Pole	5
Schmelzen der Pole	5
Schmelzen der Pole	5
Schmelzen der Polkappen	5
Schmelzen der Polkappen	5
Schmelzen und somit Verschwinden des wichtigen Nordpols	5

schmelzende Gletscher/Eisberge	5
Schmelzendes Eis	5
höhere Temperaturen	6
höhere Temperaturen	6
steigende Temperaturen	6
Temperaturanstieg	6
Temperaturerhöhung	6
Wärme	6
wärmeres Wetter	6
extreme wetterbedingungen	7
extreme Wetterlagen	7
extremes Wetter	7
Extremwetterlagen	7
heftiges wetter	7
Wetterextreme	7
Wetterextreme	7
Wetterextreme	7
Wetterextreme	7
Wetterextreme	7
veränderte Temperaturextreme	7
Klima wird wärmer	8
Klimaerwärmung	8
Klimaerwärmung	8
Klimaerwärmung	8
Klimaerwärmung	8
Umweltverschmutzung	9
Umweltverschmutzung	9
Umweltverschmutzung	9
Umweltverschmutzung	9
Umweltverschmutzung	9
Ozon	10
Ozonloch	10
Ozonloch	10
Ozonloch	10

Ozonloch	10
Ozonschicht	10
Ozonschicht	10
Dürren	12
Dürren	12
Dürren	12
Massentierhalltung	14
Massentierhaltung	14
Massentierhaltung	14
Massentierhaltung	14
Massentierhaltung	14
Viehhaltung	14
Viehzucht	14
Naturkatastrophen	17
Naturkatastrophen	17
Naturkatastrophen	17
Umweltkatastrophen	17
Umweltkatastrophen	17
Umweltkatastrophen	17
Katastrophen	17
Klimkatastrophen	17
mehr Naturkatastrophen	17
Wetteränderungen	20
Wetterveränderung	20
Wetterveränderung	20
Wetterveränderungen	20
Veränderung des Wetters	20
Veränderung von Wetter	20
Energie	22
Energiegewinnung	22
Energiegewinnung	22
Ernährung	22
Erneuerbare Energien	22
Erneuerbare energien fördern	22

Erneuerbare Energien: finden und nutzen	22
Atomkraft	22
fehlende Einsicht u bereitschaft der Menschen	23
Konsum, Industrieländer als Ursache	23
Menschen	23
Menschheit	23
menschlische Emissionen	23
moderner Mensch handelt nicht nachhaltig	23
Verursacher/Verstärker Mensch	23
von Menschen verursacht	23
Warum der Mensch seine eigene Lebensgrundlage immer weiter zerstört	23
Zerstörung der Umwelt durch den Menschen, aus unwillkürlicher "Verantwortung"	23
Zerstörung unserer Lebensgrundlage	23
Zerstörung unseres Planeten	23
Zerstörung von lebensraum	23

Source: own dataset.

B2 Farm-level risks

B2.1 Survey Questions

Original survey questions for farm-level risks:

2010 Survey: "Was ist Ihrer Meinung nach das bedeutendste Risiko in der Landwirtschaft?"

2013 Survey: "Was sind Ihrer Ansicht nach die bedeutendsten Risiken auf Ihrem Betrieb? Bitte listen Sie das aus Ihrer Sicht bedeutendste Risiko zuerst auf, oder nummerieren Sie die Risiken entsprechen ihrer Bedeutung."

B2.2 Farm-level risk statements and categories applied

Code	*Risk category*
1	Climate and weather conditions
2	Extreme weather events
3	Production risk and production practice
4	Output prices and marketing
5	Policy risks
6	Laws, regulations and local authorities
7	Dept, solvency, investment needs
8	Health- and other personal risks
9	Others
11	Input prices and land availability
13	Business structure and farmer family
14	Machinery

Source: own documentation.

Farm-level risk statements, frequency and categorization

Statement	***Category***	***Count***
climate change	1	0
climate	1	3
weather (Wetter/Witterung)	1	28
frost	1	2
wet weather during harvest	1	4
unusual weather	1	1
dry spring-weather conditions	1	2
risk of short vegetation period (maize 2013)	1	1
always extreme weather	1	1
dry spells	2	13
hail	2	12
heavy weathers	2	6
heat extremes	2	0
yield losses	3	5
cultivation of nursing-intensive crops	3	2
animal health risk	3	12
selection of cultivars/varieties	3	1
cultivation of specialty crops	3	2
cultivation of new cultivars	3	1
pests/weeds/diseases in crops	3	3
seeding time	3	1
mowing time	3	1
time for fertilizer application	3	1
output market price decline	4	13
world market developments/price decline	4	0
stock-market caused price risks	4	4
market prices	4	17
output price volatility	4	6
world market imports	4	1
marketing structures (coops)	4	1
euro-crisis	4	1

income/farm profitability (as a result of input/output prices)	4	9
time of marketing	4	2
stock keeping of grain	4	1
food scandals	4	1
demand for seed grain production decreasing	4	1
special requirements of direct marketing (quality, processing)	4	3
overproduction on domestic/local market	4	2
yield losses with contracted products	4	1
subvention policy changes	5	6
sugar market policies	5	1
(new) environmental policies and regulations, cross-compliance duties	5	6
(uncertainties related to) agricultural policy	5	4
acceptance of subsidies in society	5	1
market interferences of policy/ too much influence of policy	5	2
liability laws	6	3
restrictions from local administration (denial of permissions)	6	2
(increasing) bureaucracy	6	2
policy restrictions, regulations	6	0
over-indebtedness/investment requirements	7	5
high capital lock-up in machines	7	1
investments into processing facilities	7	1
health/outage of farm manager	8	31
ageing	8	2
work-overload	8	1
lack of joy in work	8	1
radioactivity in soils	9	1
problems in the society	9	1
public carrier	9	1
increasing prices for machinery	11	1
machine costs	11	1
land rent prices	11	10
farm land loss	11	8
input prices (incl. volatility)	11	14
farm land availability/affordability (buy farmland)	11	2

increasing input prices	11	4
competition of biogas producers for land	11	3
input price volatility	11	1
family (workforce/acceptance of occupation)	13	8
lack of successor	13	2
cooperation (GBR) with non-family members	13	1
hired labor	13	1
time-constraints hinder optimal crop-nursing (side farm)	13	1
time demand	13	2
farm too small	13	3
locations	13	1
machine breakdowns	14	3
		Total: 303

Source: own dataset.

B3 Adaptation knowledge

B3.1 Survey Questions

Original survey question for adaptation knowledge/ perceived adaptation measures:

2013 Survey: "In Ihrer Region: Welches sind Ihrer Meinung nach die besten Möglichkeiten, um sich als landwirtschaftlicher Betrieb schon jetzt gegen mögliche Folgen des Klimawandels gut aufzustellen? Bitte führen Sie kurz aus oder notieren ein paar Stichpunkte:"

B3.2 Datasets and Categories

(Contact author for datasets)

B3.3 Statistical analysis

B3.3.1 Effect of region on mean value of stated adaptation measures

	Mean of stated adaptation measures:			
	Full sample (incl. Non-responses)			**T-test value:**
obs:	region:	avg #	obs:	**0,08048473**
	SJ	1,15	82	
	K	1,45	91	

	Mean of stated adaptation measures:			
	Question responders:			**T-test value:**
obs:	region:	avg #	obs:	**0,11245049**
	SJ	2,35	82	
	K	2,03	91	

B3.3.2 Effect of age on response to the question for perceived adaptation measures

Age:

adapt_measure_yes

	yes	no	**T-test value:**
avg_age	**50,41**	**52,18**	**0,49033232**
obs	104	69	173

Age (SJ):

adapt_measure_yes

	yes	no	**T-test value:**
avg_age	**49,95**	**50,93**	**0,47407489**
obs	40	42	82

Age (K):

adapt_measure_yes	yes	no	**T-test value:**
	50,69	**54,20**	**0,3201857**
obs	64	27	91

B3.3.3 Effect of perception of climate and weather-related risks on response to the question for perceived adaptation measures

Adaptation measures mentioned:

	perceived climate risk:					
stated measure	**yes**	**no**	Total	percentages	**no**	
yes	**53**	**52**	105	0,60693642	**63**	
no	**16**	**52**	68	0,39306358	**41**	**p-value (Chi2)=**
Total	69	104	173			0,000407168

Adaptation measures mentioned (SJ):

	perceived climate risk:					
stated measure	**yes**	**no**	obs:	percentages	**no**	
yes	**18**	**22**	40	0,48780488	**26**	
no	**10**	**32**	42	0,51219512	**28**	**p-value (Chi2)=**
obs	28	54	82			0,043106536

Adaptation measures mentioned (K):

	perceived climate risk:					
stated measure	**yes**	**no**	obs:	percentages	**no**	
yes	**35**	**30**	65	0,71428571	**36**	
no	**6**	**20**	26	0,28571429	**14**	**p-value (Chi2)=**
	41	50	91			0,007697913

B3.3.4 Effect of age on perception of climate and weather related risks

Age:

Perceived climate risk

	yes	no	**T-test value:**
avg_age	**49,60**	**52,10**	**0,18692004**
obs	69	104	173

Age (SJ):

Perceived climate risk

	yes	no	**T-test value:**
avg_age	**47,26**	**52,10**	**0,07593397**
obs	28	54	82

Age (K):

Perceived climate risk			**T-test value:**
	51,15	**52,10**	**0,4854412**
obs	41	50	91

B3.3.5 Influence of main production activity on adaptation knowledge

Test statistics of the SAS (Vers. 9.4) *proc GLIMMIX*-procedure.

emph_1 Least Squares Means							
emph_1	Estimate	Standard Error	DF	t Value	Pr > |t|	Mean	Standard Error Mean
1	0.4055	0.3333	147	1.22	0.2258	1.5000	0.5000
2	0.1431	0.1826	147	0.78	0.4344	1.1538	0.2107
3	0.7419	0.2182	147	3.40	0.0009	2.1000	0.4583
4	0.8109	0.3333	147	2.43	0.0162	2.2500	0.7500
5	0.09812	0.09667	147	1.01	0.3118	1.1031	0.1066
6	0.5878	0.2357	147	2.49	0.0137	1.8000	0.4243

Source: own calculations.

Categories:

emph_1_cat			**avg_no_adapt_options**				
	Both regions	obs	SJ	obs	KR	obs	Code
1	**1,50**	6	1,40	5	2,00	1	***Other***
2	**1,15**	26	1,14	21	1,20	5	***Dairy, other cattle***
3	**2,10**	10	2,00	4	2,17	6	***Pork, poultry***
4	**2,25**	4	3,00	3	0,00	1	***grass and other fod-der***
5	**1,10**	97	0,92	38	1,22	59	***arable cropping***
6	**1,80**	10	0	0	1,80	10	***specialty crops and vegetables***

C Experiment Documentation

C1 Wording Protocols

C1.1 Wording protocol random experiments

Regular fond: Instruction
Regular fond in italics: Information for experimenter (not pronounced)
Bold fond in italics: Instruction that is to be pronounced with emphasis

Instructions were printed on instruction cards. '--' indicates where the cards started and ended

--
We will now conduct a simulation experiment with you.
By means of this experiment we try to find out how expectations about weather and climate are built and how they influence cropping decisions.
For doing so, the situation in the experiment is such that you are a farm decision maker, as you are in your real life. Arable production is the single production branch of your farm. The experiment will be about deciding between four cropping options – which represent four annual cultivars – in each year. But you will hear more on that later on.

What will be the topic now is the weather in the experiment? The experiment will run over twenty cropping years. On your farms occur – for reasons of simplification – only two weather conditions. They are "good weather" and "bad weather" and always account for the entire year.

--
Thereby, climate and the ensuing yearly weather condition is represented – as you can see here – by different distributions of colored balls. *(The different distributions of balls are contained in three glass cylinders positioned on a table in front of participants)*

From one of these distributions we will later on draw a ball in every year of the experiment. Afterwards, the ball will be put back. Thereby, a green ball represents a year with good weather and a red ball represents a year with bad weather.
At the beginning of the experiment you are in the situation that you know very well which weather to expect for the location of your farm, because you ran that farm already for a long time. Therefore, you know from experience that years with bad weather occur as often as years with good weather conditions on average. This situation is symbolized by this distribution of balls which contains the ratio of 5 green and 5 red balls, as you see here.

(A glass cylinder with the label "initial climate" is used to present the distribution to participants)

From this distribution of balls the weather will be determined by random drawing during the initial phase of the experiment. Subsequently the ball will be put back, so that the distribution remains unchanged.

[The experimenter takes the balls from the cylinder and put them into a black and opaque bag and attaches the label „initial climate“ from the cylinder to it]

However, in the course of the experiment, climatic changes will occur.

--

Scientists who inform you about the climatic change tell you that this change is to be expected, but they cannot tell if the climate to eventuate in the coming years will be advantageous or disadvantageous for agricultural production conditions in your location.
The scientists assess an advantageous climate for the coming years as equally likely as the emergence of a climate that is less favorable for agriculture.
This situation is represented by these two distributions of balls:
(Two glass cylinders labeled "advantageous climate" and "disadvantageous climate" are used to present the distributions to participants)

This distribution contains 6 green balls and 4 red balls, which stands for an advantageous future climate. The other distribution contains 4 red and 6 green balls, which represents an adverse future climate.
[The experimenter points at the respective distribution]

Both climates are now filled in these two neutral and opaque bags.
[The experimenter fills each of the distributions into one of two equally looking, black and opaque bags]

Since the event of both climatic conditions is judged equally likely and the future situation therefore is judged as unknown, we will now mix the two bags under the table.
[The experimenter exchanges the bags several times from one hand to the other in a hidden procedure under the tabletop of a desk]

--

Now we will toss a coin to randomly select from which of the two bags the weather will be determined after climate change set in. In case the head side of the coin is up, we will select the left bag, in case of tails the right.

[The experimenter tosses a coin and selects one of the bags accordingly]

Interposed question: Do you believe that we have no control over which of the possible distributions has been selected to be in the experiment? [*In case doubts are expressed the procedure has to be repeated.]*

--

1 Elements of the Experiment

1.1 Crops

Please consider now the table in the projection.

As you can see from the table, the arable farm you run throughout our experiment is 50 hectares large. This means each one of you has 50 hectares of arable land at disposal, which is separated into five equal large plots. Each plot is 10 hectares.
[The experimenter points at the respective cells of the table in the projection]

You have four cropping options which –as said before – represent four annual crops. The crop alternatives are - as you can see here *[The experimenter points at the respective cells of the table in the projection]* – labeled J, K, B and L. They only differ with regard to the yearly gross margin they can reach, which depend on the weather conditions of the respective year.

--

1.2 Weather and gross-margins

On your farm the weather has at the basis of a whole year – as said already – only two weather outcomes, namely “good” or “bad”.
[The experimenter points at the respective cells of the table in the projection]

The consequences are the gross margins per 10 ha plot depicted in the following table for each crop. Depicting gross margins per 10 hectare-plots may be a little unconventional but it saves a bit of calculation effort and is therefore practical.

*[The experimenter reads out the **name of each crops and the respective gross margins loudly and clearly**.]*

	J	**K**	**B**	**L**
GM/10 ha plot „good weather“	16 000€	12 000€	8 000€	5 000€
DB/10 ha plot „bad weather“	-4 000€	-1 000€	2 000€	4 200€

Which weather eventuates in which year will be determined by us via the draw of a ball from a bag in each year, while a green ball symbolizes a year with good weather, a red ball stands for a year with a bad weather outcome.

--

1.3 Weather expectations

Besides cropping decisions your appraisal of weather conditions is at the focus of this simulation experiment, we ask you in every year to think well about which weather outcome you expect for this year, before you set the mark in the box *[The experimenter* *points at the cell "expected weather"]* "expected weather" at one of the following fields: "good", "bad", or "no statement possible".

Thereby, it does not have priority if you are right or wrong. For us it is much more important to get a proper statement on the expectation you have at the time of your decision. You can – and you should – think about your weather expectation carefully in each round/each year and check what seems most likely for you at that moment.

Please push later during the experiment "finished" *[The experimenter points at the button "finish"]* every time you are done with making up the cropping plan for a year and you do not want to change anything anymore.

--

1.4 Crop rotations and other restrictions

One important note on cropping options: in our experiment no specific crop rotations are necessary since no yield decrease occur if the same crop is grown several times at the same plot. Also, other framework conditions in agriculture have changed essentially.

Cross compliance regulations, maximum acreage restrictions for certain crops as well as set-aside requirements or the like do not hold for our experiment.

--

2. Economic conditions

Under which economic conditions are the decisions taken in the experiment?

2.1 Initial credit

As you can see here *[The experimenter points at the cell "current credit"]*, you are starting with an initial credit of 30 000€.

2.2 Sum of cross margins

In this box *[The experimenter points at the cell "sum of cross margins/year"]*, the sum of gross margins you gained with your cropping decisions will be calculated automatically every year, after the weather outcome of this year has been determined by random drawing.

--

2.3 Fix cost

You need a yearly income of €10 000 for covering the fix cost of your farming business [*The experimenter points at the cell "yearly fix cost"]*. This amount will be automatically deducted from the sum of cross margins you earned in a year.

2.4 Current credit

Your surplus to this fix cost is your income of each year and contributes to your current credit. [*The experimenter points at the cell "current credit"]*

As it is in real life, your credit may also decrease. This happens in case the fix cost of €10 000 cannot be covered by the gross margins you earn in one year.

You can always read your current amount of credit from the row “current credit”. *[The experimenter points at the cell “current credit”]*

--

2.5 Credit and payout

Attention, this is important information: The experiment will now be conducted over 20 “years” under changing conditions. For creating a relation of the decisions taken in the experiment to reality, the credit you earned during the experiment will be converted by a factor of /10 000 at the end of the experiment and be paid out to you as real money rounded to the next full Euro. This means that if you have a credit of €380 000 at the end of the experiment, you will get 38 real Euros to take home.

The maximum payout is at 50€ at a credit of €500 000 or more earned in the experiment.

2.6 Bankruptcy

Attention, here is one more important information: If your total credit decreases below zero at one point during the experiment, you are bankrupt and have to quit the experiment. If this is the case, it will be announced on your screen. In this case you will ***not*** receive a payout.

--

3 Experimental procedure

3.1 Compiling the cropping plan

We will now ask you in each year to make a cropping decision for each of your 10 hectare plots by marking one of the four cropping alternatives for each of your five plots by clicking.

If you do not want to change your cropping plan anymore, then please mark your weather expectation for this year and click “done”.

Subsequently, we will determine the weather to occur for this year by drawing from the bag.

--

3.2 Displays

Now, we will quickly explain the summary displays on your screen. In this box *[The experimenter points at the cell “weather” in the projection]* – after you finished your cropping plans and the weather has been determined - the weather will be displayed for each year.

The sequence of weather outcomes, an overview of your cropping decisions of the previous years, as well as your yearly incomes of the previous years will be displayed here to the left of your screen *[The experimenter points at the respective headlines of the overview table in the projection]*

--

3.3 Individual decision

Before we start now, some more important information: As mentioned before, the experiment will run over 20 years. This will require a little less than one hour. ***Since all participants have the same information during the experiment, it is not worthwhile to watch your neighbor's decisions or the ones of the persons in front of you. We would ask you therefore to make the decisions on your own and not to talk to other participants in the course of the experiment.***

We also request not to give comments when the experiment is in progress.

In case you face a problem at any time during the experiment - for instance, if you don't know how to proceed - please notify this by raising your hand.

--

4 Starting the experiment

Let us start the experiment.

4.1 log-on

Please register now by entering your participant number in the box "user id" and afterwards click "register".

[The assistant at the computer repeatedly clicks "update" and unlocks the experiment when all participants are registered.]

All participants are now registered. Please now click "continue".

You see now the cropping plan for year one.

--

4.2 Initial Situation

You are now in the initial situation in which you are very well versed with the weather conditions.

As just introduced, this situation is represented by a known composition of 5 green und 5 red balls in this bag *[The experimenter takes the bag with the tag "initial climate" and shows it to the participants]* from which from now on will be drawn.

Year 1:

We are now situated in year 1.

Please start now filling in the cropping plan for the first year.

Give enough time…
Please then enter a weather expectation.

Give enough time…

--
Please click “complete” when you are done with compiling the cropping plan.
[The assistant repeatedly clicks “update” and signalizes when all cropping plans are submitted.]

All cropping plans have been submitted. Now the weather will be determined by drawing from the bag.
[The experimenter mixes the balls by shaking the bag. The assistant takes an obviously random draw by turning their face away and drawing a ball from the bag which is held towards her by the experimenter]

The weather of the first year is …

Now the weather will be entered. *[The assistant enters the weather outcome]*
The weather has been entered. Now please click “continue” to see your annual result for the first year.

Give enough time…
By clicking “continue” you proceed to the cropping plan for the next year.

--
Year 2-5:
Now we proceed to the second *(/nth)* year. Please think over your cropping plan and make your cropping decisions.

Please enter your expectation about the weather.

Please click “complete” when you are done with compiling the cropping plan.
All cropping plans have been submitted. The weather of the *nth* year is…

Now the weather will be entered. *[The assistant enters the weather outcome]*

The weather has been entered. Please click now “continue” to see your annual result for the nth year.

By clicking “continue” you proceed to the cropping plan for the next year.

--

4.3 First climatic change

Year 6:

A climatic change occurs. *[The experimenter puts the bag aside]*

As scientists predicted, the climate in your location changes. The scientists cannot tell you if future climate will be advantageous or disadvantageous for agricultural production conditions in your location.
This situation is represented by the two distributions of balls we presented before.
As a reminder: One distribution contains 6 green balls and 4 red balls, which stands for an advantageous future climate. The other distribution contains 4 red and 6 green balls, which represents an adverse future climate.

One of these two possible distributions is now in this bag *[The experimenter shows the bag that was previously selected during the random procedure]* and neither you nor we know which one it is.

--

Introduction of climate expectation

Now, for the following rounds we would request you - in addition to your expectation of the weather realization in each respective year - to enter an appraisal of the underlying climate, i.e. an appraisal of which one of the bags is in play.

You do this in the new field “expected climate” which you will find from now on under the already familiar field “expected weather”.

Please select “good” if you assume that the bag with 6 green and 4 red balls is in play and “bad” if you assume the bag with 4 green and 6 red balls to be in play.

Please select “no statement possible” only if you really feel that you can say nothing about which bag and, which climate respectively, is likely in play.
[The assistant unlocks the cropping plan for year 6]

The cropping plan for year six is now enabled.

--

Year 6-15:

Please make your cropping decisions now for year …n …!
Then please enter your weather expectation for the current year.
Then please enter which climate you assess to be most likely in the current year (i.e. from which bag the weather is determined according to your opinion).

Now please click “complete” when you are done with compiling the cropping plan.
Again, the weather will be determined by drawing from the bag.

[The experimenter mixes the balls by shaking the bag. The assistant makes an obviously random draw by turning her face away and drawing a ball from the bag which is held towards her by the experimenter]

The weather of the nth year is …

Now the weather will be entered. *[The assistant enters the weather outcome]*
The weather has been entered. Please click now "continue" to see your annual result for the nth year.
By clicking "continue" you proceed to the cropping plan for the next year.
--
Year 16:
You are now situated in the 16th year of the experiment and again the climatic conditions at your location change.

In addition to the two yearly weather conditions you are already familiar with (good and bad weather) there will be years with extreme weather conditions occurring in the future, which we name "very bad".

These weather events influence the gross margins of the crops you have available. If a year with a very bad weather occurs the crops will yield the following gross margins:

	J	K	B	L
GM/plot „very bad weather"	-5000€	-3000€	1000€	4000€

[The experimenter points at the respective cells of the table in the projection]
This weather condition is symbolized by two yellow balls which we will now put to the existing climatic condition into the bag.

[The experimenter shows the two yellow balls and put them into the bag]
Please consider this for the cropping decisions for the coming years.

[The assistant unlocks the cropping plan for year 16]
The cropping plan for year sixteen is now enabled.

--
Year 16-20:
Please make your cropping decisions now for year …n …!
Then please enter your weather expectation for the current year.
Then please enter which climate you assess to be most likely.

Please click "complete" when you are done with compiling the cropping plan.
The weather will be determined.

[The experimenter mixes the balls by shaking the bag. The assistant makes an obviously random draw by turning her face away and drawing a ball from the bag which is held towards her by the experimenter]

The weather of the nth year is …
Now the weather will be entered. *[The assistant enters the weather outcome]*

The weather has been entered. Please click now "continue" to see your annual result for the nth year.

By clicking "continue" you proceed to the cropping plan for the next year.

--
4.5 End of the experiment
When year 20 is completed:
Here you see the figures for final wealth you achieved in the experiment.
[The experimenter points at the list featuring participant numbers and final credit values in the projection]

Each participant sees the list of final credit values and participant numbers on her screen as well. The row that accounts to the participant is highlighted.
[The experimenter takes the balls out of the bag and presents them to the participants]

C1.2 Wording protocol repetition experiments

Regular fond: Instruction
Regular fond in italics: Information for experimenter (not pronounced)
Bold fond in italics: Instruction that is to be pronounced with emphasis
Instructions were printed on instruction cards. '--' indicates where the cards started and ended

--
We will now conduct a simulation experiment with you.
By means of this experiment we try to find out how expectations about weather and climate are built and how they influence cropping decisions.

For doing so, the situation in the experiment is such that you are a farm decision maker. Arable production is the single production branch of your farm. The experiment will be about deciding between four cropping options – which represent four annual cultivars – in each year. But you will hear more on that later on.

What will be the topic now is the weather in the experiment? The experiment will run over twenty cropping years. On your farms occur – for reasons of simplification – only two weather conditions. They are “good weather” and “bad weather” and always account for the entire year.
--
Thereby, climate and the ensuing yearly weather condition is represented – as you can see here – by different distributions of colored balls. *(The different distributions of balls were contained in three glass cylinders positioned on a table in front of participants)*

From one of these distributions we determined the weather condition of each year during an earlier run of the experiment with farmers, by random drawing and subsequently putting back the ball. A green ball represents a year with good weather and a red ball represents a year with bad weather.

We will now conduct the experiment with you under identical conditions, however with the already determined sequence of weather conditions. In order to do this, we will now present to you how the sequence of weather outcomes which will be underlying our experiment today was realized.

The situation in the experiment is such that at the beginning of the experiment you are in the situation that you know very well which weather to expect for the location of your farm, because you already ran that farm for a long time. Therefore, you know from experience that years with bad weather occur as often as years with good weather conditions on average. This situation is symbolized by this distribution of balls which contains the ratio of 5 green and 5 red balls, as you see here.

(A glass cylinder with the label "initial climate" is used to present the distribution to participants)

This distribution of balls was filled in an opaque bag from which during the initial phase of the experiment the weather conditions for each year were determined via random drawing.

--

Farmers were told before the beginning of the experiment – as you are told now – that in the course of the experiment climatic changes will occur. Scientists who inform you about the climatic change tell you that this change is to be expected, but they cannot tell if the climate to eventuate in the coming years will be advantageous or disadvantageous for agricultural production conditions in your location. The scientists assess an advantageous climate for the coming years as equally likely as the emergence of a climate that is less favorable for agriculture.

This situation is represented by these two distributions of balls:

(Two glass cylinders labeled "advantageous climate" and "disadvantageous climate" are used to present the distributions to participants)

This distribution contains 6 green balls and 4 red balls, which stands for an advantageous future climate. The other distribution contains 4 red and 6 green balls, which represents an adverse future climate.

[The experimenter points at the respective distribution]

Both possible distributions were then filled as well into these neutral, opaque bags.

[The experimenter fills each of the distributions into one of two equally looking, black and opaque bags]

Since the event of both climatic conditions is judged equally likely and the future situation therefore is judged as unknown, **the two bags were then mixed under a table**.

[The experimenter exchanges the bags several times from one hand to the other in a hidden procedure under the tabletop of a desk]

--

Subsequently, a coin was tossed in order to randomly select the bag from which the weather was to be determined after the climatic change occurred. In case heads was up the left bag was chosen, in case tails the right bag was chosen.

[The experimenter tosses a coin and selects one of the bags accordingly]

Interposed question: Do you believe that we **had** no control over which of the possible distributions **had been** selected to be in the experiment? *In case doubts are expressed the demonstration of the procedure has to be repeated.*

By this procedure the bag was chosen from which the sequence of weather outcomes was determined by random, hidden drawing and subsequent putting back of the

ball, in order to keep the distribution unchanged. This sequence would also occur in our experiment after climate change set in.

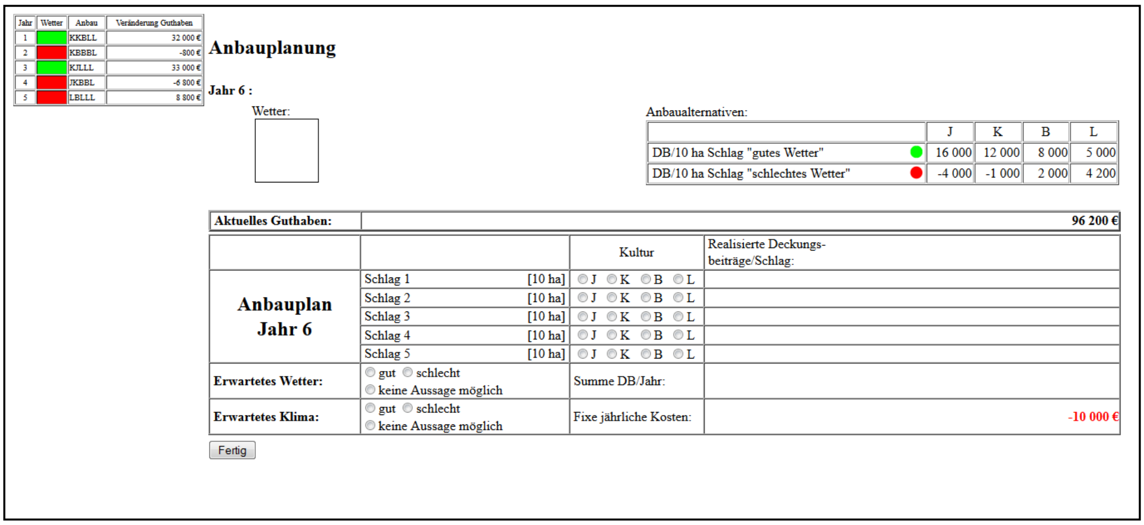
--

Description of elements of the experiment and implementation further on was identical with the one conducted in the random experiments.

C2 Implementation

C2.1 Cropping plan

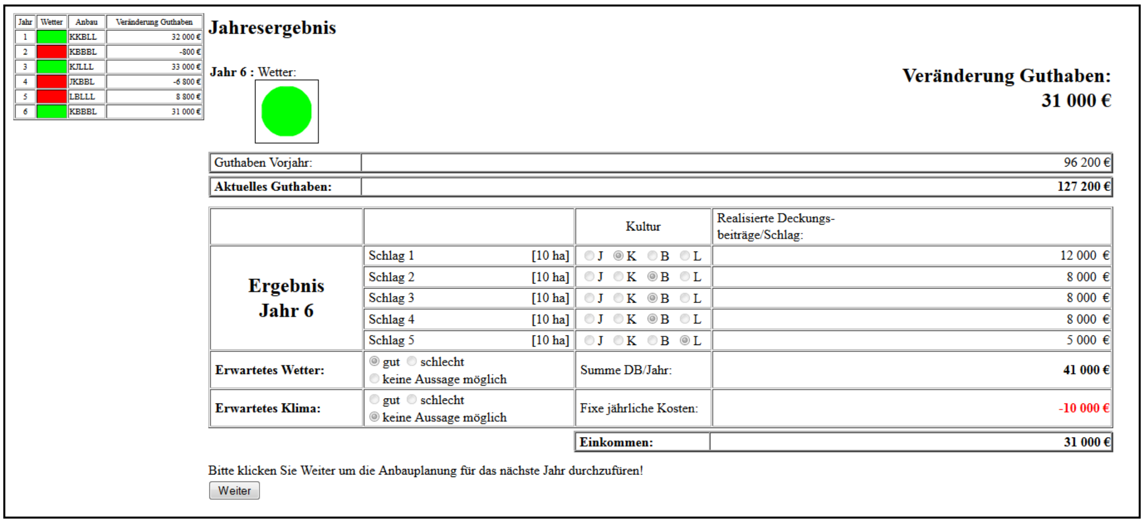
User interface display ‘Cropping plan’ to be filled in by participants at the beginning of each period of the experiment.



Source: own source (screenshot of browser display).

C2.2 Yearly income sheet

User interface display of the summary form participants received after each period's weather realization.



Source: own source (screenshot of browser display).

C3 Statistical analysis

C 3.1 Test for association of categorical data - Influence of participant status

Test statistics for test of independence between the categorical variables 'participant status' (1- farmer; 2 - farmer school student; 3 - university student) and 'expectation model assigned', based on *Fisher's exact test* for r x c tables (STATA, Vers. 12).

```
. tabulate status expec_model, exact


                              180204_expect_models
           |                         expec_model
    status |         0          1          2          3          4 |     Total
-----------+-------------------------------------------------------+----------
         1 |        10          3          0          0          1 |        15
         2 |         4          4          2          3          2 |        17
         3 |        18         22          2         11          2 |        65
-----------+-------------------------------------------------------+----------
     Total |        32         29          4         14          5 |        97

           |                    expec_model
    status |         5          6          7         10 |     Total
-----------+--------------------------------------------+----------
         1 |         0          1          0          0 |        15
         2 |         0          1          1          0 |        17
         3 |         1          1          0          8 |        65
-----------+--------------------------------------------+----------
     Total |         1          3          1          8 |        97

           Fisher's exact =                 0.032
```

C 3.1.1 Coding information

```
**codes:
**status: 1 - farmer; 2 - farmer school student; 3 - university student

** expec_model: 0 - unexplained; 1 - rational & rational cannot be refused;
** 2 - risk aversion ; 3 - bias adverse climate ; 4 - bias favorable climate;
** 5 - small sample; 6 - tolerance; 7 - naive; 10 - ambiguous alt. mechanism.
```

C3.2 Test for association of categorical data in stratified samples - Influence of climate in the experiment

Test statistics for test of independence between the categorical variables 'sequence received' (A-D) and 'expectation model assigned', controlling for participant status based on the SAS *proc freq*-procedure (Vers. 9.4).

The SAS System

The FREQ Procedure

Summary Statistics for sequence by expec_model
Controlling for status

Cochran-Mantel-Haenszel Statistics (Based on Table Scores)				
Statistic	Alternative Hypothesis	DF	Value	Prob
1	Nonzero Correlation	1	0.5741	0.4486
2	Row Mean Scores Differ	3	1.7554	0.6247
3	General Association	24	33.7374	0.0894

Total Sample Size = 97

Source: own calculations.

C3.3 Test for association of ordered categorical data - Influence of participant age

C3.3.1 Significance of age_cat1

Test statistics for test of independence between the ordinal categories of 'age_cat1' (15-29; 30-44; 45-59; >60) and the categorical variable 'expectation model assigned' based on the SAS *proc freq*-procedure (Vers. 9.4).

Statistics for Table of agecat by expec_model

Statistic	DF	Value	Prob
Chi-Square	24	17.0507	0.8465
Likelihood Ratio Chi-Square	24	17.6817	0.8182
Mantel-Haenszel Chi-Square	1	2.3203	0.1277
Phi Coefficient		0.4214	
Contingency Coefficient		0.3884	
Cramer's V		0.2433	

WARNING: 89% of the cells have expected counts less than 5. Chi-Square may not be a valid test.

Effective Sample Size = 96
Frequency Missing = 1

Source: own calculations.

C3.3.2 Significance of age_cat2

Test statistics for test of independence between the ordinal categories of 'age_cat2' (15-24; 25-39; 40-54; >55) and the categorical variable 'expectation model assigned' based on the SAS *proc freq*-procedure (Vers. 9.4).

Statistics for Table of agecat2 by expec_model

Statistic	DF	Value	Prob
Chi-Square	24	24.0723	0.4575
Likelihood Ratio Chi-Square	24	22.5026	0.5493
Mantel-Haenszel Chi-Square	1	1.2807	0.2578
Phi Coefficient		0.5008	
Contingency Coefficient		0.4478	
Cramer's V		0.2891	
WARNING: 89% of the cells have expected counts less than 5. Chi-Square may not be a valid test.			

Effective Sample Size = 96
Frequency Missing = 1

Source: own calculations.

Curriculum Vitae

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Education

2011	**Master of Science** in Agricultural Sciences (Agricultural Economics) *Universität Hohenheim* (including studies at the University of Illinois at Urbana Champaign, Illinois, US)
2008	**Bachelor of Science** in Agricultural Sciences *Universität Hohenheim*
2003	**Abitur** *Edith-Stein-Schule*, Ravensburg (Agrarwissenschaftliches Gymnasium)

Professional Experience

2016 - Present	**Research Associate** *Dep. Land Use Economics in the Tropics and Subtropics (490d), Universität Hohenheim*
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2009 - 2011	**Student Assistant** *Dep. Land Use Economics in the Tropics and Subtropics (490d), Universität Hohenheim* DFG Project PAK 346: "Structure and Functions of Agricultural Landscapes under Global Climate Change - Processes and Projections on a Regional Scale", Subproject P6: "Agent-based modelling and assessment of human-environment interactions"
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Eidesstattliche Versicherung

gemäß § 8 Absatz 2 der Promotionsordnung der Universität Hohenheim zum Dr.sc.agr.

1. Bei der eingereichten Dissertation zum Thema

'Investigating Climate Change Perception and Expectation Formation for the Advancement of Agent-Based Models Applied to Agricultural Adaptation Assessment'

handelt es sich um meine eigenständig erbrachte Leistung.

2. Ich habe nur die angegebenen Quellen und Hilfsmittel benutzt und mich keiner unzulässigen Hilfe Dritter bedient. Insbesondere habe ich wörtlich oder sinngemäß aus anderen Werken übernommene Inhalte als solche kenntlich gemacht.

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