Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt

Lehrstuhl für Produktions- und Ressourcenökonomie landwirtschaftlicher Betriebe

The Economic Implications of Climate Change: An Analysis of Smallholder Farming Systems in Ethiopia

Lemlem Teklegiorgis Habtemariam

Vollständiger Abdruck der von der Fakultät Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt der Technischen Universität München zur Erlangung des akademischen Grades eines Doktors der Agrarwissenschaften genehmigten Dissertation.

Vorsitzender: Prof. Dr. Johannes Sauer

Prüfer der Dissertation:

1. Prof. Dr. Alois Heißenhuber
2. Prof. Dr. Thomas Knoke
3. Priv.-Doz. Dr. Markus Gandorfer

Die Dissertation wurde am 23.08.2018 bei der Technischen Universität München eingereicht und durch die Fakultät Wissenschaftszentrum Weihenstephan für Ernährung, Landnutzung und Umwelt am 23.01.2019 angenommen.

Table of Contents

List of Tables

List of Figures

List of Abbreviations

CO_2- Carbon dioxide

CSA- Central Statistical Agency

GCMs- General Circulation Models

GDP- Gross Domestic Product

IPCC- Intergovernmental Panel on Climate Change

NAPA- National Adaptation Program of Action

RAP-Representative Agricultural Pathways

RCP- Representative Concentration Pathways

TOA-MD- Tradeoff Analysis for Multi-Dimensional Impact Assessment

UNFCCC- United Nation Framework Convention on Climate Change

WTO- World Trade Organization

Acknowledgements

I would like to express my appreciation to all the people who have contributed during my PhD study in one or another way. Foremost, my sincere gratitude goes to Prof Alois Heißenhuber for giving me the opportunity to work on my PhD research proposal and for all his continuous academic guidance over the years. I thank him for sharing his knowledge and constantly pushing my horizon to always consider the bigger picture of my research. His support with the many administrative matters is greatly appreciated without which this work would not have been possible. I would also like to extend my great appreciation to Dr Markus Gandorfer. I thank him for his great scientific support, guidance and encouragement over the years. I also like to thank him very much for his advises and tips on career matters. Similar profound appreciation extends to Dr Getachew A. Kassa for devoting his time to provide extensive scientific support and feedback during the entire PhD phase.

I would like to acknowledge the people who have helped and facilitated many things for me during the data collection period, all the farmers for their cooperation, and the people who helped with official data and supporting materials. I also thank all my colleagues who have created a nice work atmosphere, encouraged, supported and advised me in many different ways particularly Monika, Karin, Maria and Habtamu. My special thanks goes to Erin, thank you very much for your support, I am grateful for all the discussion we had during this time, it was great to have you as office mate.

I especially would like to thank a lot Dr Stefan Sieber from ZALF who I met on the last stage of my PhD, for his academic, leadership and networking skills and experiences he shared to me. I am also very grateful about the many other colleagues that I worked with at the institute of socio-economics, ZALF for providing me quite a new and unique research experience, and excellent working atmosphere on the final stage of my PhD.

I gratefully acknowledge my funding source Katholischer Akademischer Ausländer-Dienst (KAAD). The seminars provided to us by KAAD on various global and societal issues have well complemented my PhD study. I also like to acknowledge the funding support that I received from the Laura Bassi award of TUM.

Sorelle and Mona thank you very much for your friendship, it was great that you were present in Freising, you helped me to strive. I am grateful about all the people I met at Blumen str, people from all over the world and working on research topics from different academic backgrounds; hearing about their research and cultures was very exciting and it changed my perspective a lot. Yenehiwot and Alem thanks a lot for your constant encouragement and advices in various matters, you have been an inspiration.

My deepest gratitude goes to my family and friends whose love, thought and support from afar sustained me this far. Last but not least, my greatest appreciation to my husband Dawit Ashenafi, for all your patience, and unconditional support and love you provided me during the whole process of the PhD.

I dedicate this dissertation to my mother, Amsale Abreham, for her great enthusiasm for education, for the educational opportunities she dreamed but has not gotten to pursue so far.

Summary

Farming in many parts of the world is facing many technological, institutional, and environmental challenges including the risks of climate change that have significant impact on food production and farm income. In this PhD research, the impact of climate change and climate change perception and adaptation decisions of smallholder farmers are investigated. The study focuses on a smallholder farming system in Ethiopia, a farming system commonly found in many developing countries. The unique conditions and features of smallholder farming systems, i.e., the complexity and the heterogeneity in agro-ecology, production activity, farm and household characteristics, and the limited capacity to adapt to climate change present a major interest in climate change impact and adaptation research. The studies included in this dissertation used data from household survey collected from 300 smallholder farmers in Dugda and Welmera districts of Ethiopia; long-term meteorological data; future climate change data and official historical yield statistics.

The economic impact of climate change on farms is a curial issue in the climate change literature and a major factor that shape climate policy decisions both at national and global level. In the first study, the impact assessment method applied to model the economic impact of climate change addresses the issue of farm heterogeneity in terms of physical environment, production activity, and socio-economic characteristic taking into consideration the role of agro-ecological differences. The approach is founded on modelling the impact of climate change on individual crop yields that have different sensitivity to climate change; and incorporating future local socio-economic development scenarios in the analysis. The finding illustrated well the importance of modelling crops that have different sensitivity to climate change, the significance of accounting

for farm and agro- ecological differences and consideration of future socio-economic development scenarios. It is found that the proportion of farms that would be negatively affected by climate change ranged between 51% to 78% in warm regions (e.g., Dugda) under different scenarios; in cool regions (e.g., Welmera) the proportion of negatively affected farms ranged between 10% to 22%. The percentage of negatively affected farms indicates the proportion of farms that are negatively impacted with a loss in net return due to climate and socio-economic changes. Understanding this heterogeneity in impact of climate change is relevant to make informed decision on adaptation priorities and mitigation actions.

In the second study, an econometric modeling is applied to investigate the various factors, which influence the climate change perception of smallholder farmers and to explain why farmers would have different perception about climate change. The climate change perception modelling approach is grounded on theories and concepts (e.g., theory of motivated reasoning) that explain the link between perception and prior climate change information, variables that constrain or aid access to information, variables that affect analytical skills and information processing, and previous relevant empirical findings. It is found that perception about climate change is linked to various individual and farm level characteristics and geographical variables. The econometric models illustrate statistical significance for explanatory variables including location, gender, age, education, soil fertility status, climate change information, and access to credit services. By understanding the factors that influence farmers' climate change perception policy makers can develop effective strategies to enrich the knowledge of farmers about the causes of climate change, its impacts and appropriate mitigation and adaptation measures.

In the third study, the climate change adaptation literature that focuses on smallholder agriculture is reviewed. Emphasis is given to conceptual foundations, methodological approaches and findings of the available literature. It is found that the adaptation literature is growing and evidences are emerging that shed light on our understanding of the potentials and costs of adaptation, the process of farm level adaptation decisions, and the link between development planning and poverty reduction strategies. Nonetheless, there are issues that need further investigation. For example, the conceptual foundations need to be expanded taking into account other relevant variables (such as cognitive factors, psychological variables, risk perception and experience variable) that influence adaption decisions. To address data limitations, devising methods that are robust but require minimum data would be essential.

In the fourth study, a model of farmers' adaptation decision is developed to empirically investigate the role of risk experience and other resource and information related variables. The study bases itself on the perceived risk appraisal concepts of adaptation decision process, which is derived from the protection motivation theory. The study hypothesized that factors such as risk experience and perception influence the climate change adaptation behavior of smallholder farmers. Thus, if risk experience and perception reduce the uncertainty associated with the occurrence and severity of climate change risk, it may increase the likelihood of the decision to adapt. The econometric modelling applied in the study showed that certain type of risk experiences such as experience of agricultural production shocks is an important variable in adaptation decisions of smallholder farmers. Socio-economic (gender, education and household size), institutional (agricultural extension service) and agro-ecological variables are also found to be associated with adaptation decisions. Risk perception is a relevant variable for policy intervention as it can be influenced by risk communication strategies.

In general, the findings of the studies suggest that detailed site-specific information helps to better understand the impact of climate change, which suggest the importance to do more research addressing diverse agro-ecologies, socio-economic conditions and production activities. Also, climate change perception and adaption decisions are highly shaped by site and household specific factors. The findings signify the need for climate change information provision particularly targeting farm households that are less likely to perceive changes in climate change; this can be done by considering local conditions and demographic characteristics such as farmers' education level, gender, and age. The findings also indicate that unless appropriate measures are taken the livelihoods of many farmers, particularly in warm regions are threatened. Therefore, it is important to take appropriate agricultural interventions giving priorities to warm regions. It is also recommended that policy makers can use risk communication strategies that provide clear messages on the future risks of climate change to motivate farmers for adaptation.

Zusammenfassung

Die Landwirtschaft steht in weiten Teilen der Welt vor erheblichen technologischen, institutionellen und ökologischen Herausforderungen, nicht zuletzt durch die Risiken des Klimawandels, die einen signifikanten Einfluss auf die Nahrungsmittelproduktion und auf die Einkommenssituation von landwirtschaftlichen Betrieben haben. Im Rahmen dieser Dissertation werden die Folgen des Klimawandels und die Wahrnehmung klimatischer Veränderungen durch Kleinbauern und ihr Entscheidungsprozess bezüglich geeigneter Anpassungsmaßnahmen untersucht. Die Arbeit widmet sich dem kleinbäuerlichen Produktionssystem Äthiopiens, das in vergleichbarer Form in vielen Entwicklungsländern anzutreffen ist. Für die Erforschung der Klimawandelfolgen und die entsprechenden Anpassungsleistungen sind kleinbäuerliche Produktionssysteme mit ihren spezifischen Bedingungen und Eigenschaften von besonderem Interesse – wegen ihrer komplexen und heterogenen Voraussetzungen, was Agrarökologie, Produktionsaktivitäten, Haushaltscharakteristika und die begrenzten Ressourcen zur Anpassung an den Klimawandel betrifft. Die Datengrundlage für die in dieser Dissertationsschrift enthaltenen Studien lieferten die Befragung von 300 Kleinbauern in den äthiopischen Distrikten Dugda und Welmera, Zeitreihen meteorologischer Daten, zukünftige Klimaszenarien sowie offizielle Ertragsstatistiken der Vergangenheit.

Die ökonomischen Auswirkungen klimatischer Veränderungen auf landwirtschaftliche Betriebe sind ein wichtiges Thema der Klimawandelforschung und bestimmen auf nationaler und internationaler Ebene maßgeblich die Klimapolitik. Der im Rahmen der ersten Studie verfolgte Ansatz zur Modellierung der ökonomischen Auswirkungen klimatischer Veränderungen berücksichtigt die Heterogenität kleinbäuerlicher Betriebe hinsichtlich ihrer natürlichen Produktionsbedingungen, ihrer Produktionsaktivitäten und ihrer sozioökonomischen

Eigenschaften und bezieht auch die Bedeutung agrarökologischer Unterschiede ein. Der Ansatz gründet auf einem Modell zu den Auswirkungen des Klimawandels auf die Naturalerträge landwirtschaftlicher Kulturen mit unterschiedlicher Sensibilität für klimatische Veränderungen, unter Berücksichtigung sozioökonomischer Entwicklungsszenarien. Die Ergebnisse der Studie zeigen mehr als deutlich die Bedeutung zu modellieren die Naturalerträge landwirtschaftlicher Kulturen mit unterschiedlicher Klimawandel-Sensibilität, aber auch, wie wichtig es ist, die unterschiedliche Struktur der landwirtschaftlichen Betriebe und der Agrarökologie zu beachten und sozioökonomische Entwicklungsszenarien einzubeziehen. In den wärmeren Regionen (z. B. Dugda) wird der Klimawandel der Studie zufolge 51% bis 78% der kleinbäuerlichen Betriebe betreffen – das heißt durch klimatische und sozioökonomische Veränderungen negative wirtschaftliche Auswirkungen haben –, in kühleren Regionen (z. B. Welmera) gilt dies dagegen nur für 10% bis 22% der Betriebe, jeweils abhängig vom zugrunde gelegten Szenario. Die Erkenntnis dieser unterschiedlichen Folgen des Klimawandels ist die Voraussetzung fundierter Entscheidungen über die vordringlichen Maßnahmen zur Anpassung und Schadensminimierung.

In der zweiten Studie werden mithilfe eines ökonometrischen Ansatzes die Faktoren erforscht, welche die Wahrnehmung des Klimawandels durch Kleinbauern in Äthiopien beeinflussen und zu einer unterschiedlichen Wahrnehmung des Klimawandels führen. Der Ansatz der Modellierung der Klimawandelwahrnehmung basiert auf Theorien und Konzepten (etwa der *Theory of Motivated Reasoning*), die erläutern, wie die individuelle Wahrnehmung beeinflusst wird durch vorhandene Informationen über den Klimawandel, durch Variablen, die den Zugang zu Informationen begünstigen oder begrenzen, durch Variablen, die die Fähigkeit zu Analyse und Informationsverarbeitung beeinflussen, und durch bereits vorhandene Erfahrungswerte. Die Studie zeigt, dass die Klimawandelwahrnehmung von diversen persönlichen und betrieblichen Faktoren, aber auch von geografischen Faktoren determiniert wird. Die ökonometrische Analyse weist eine statistische Signifikanz einer Reihe von Variablen wie etwa Ort, Geschlecht, Alter, Ausbildung, Bodenfruchtbarkeit, Wissen über den Klimawandel und den Zugang zu Krediten nach. Die Kenntnis dieser Zusammenhänge erlaubt es Politikern, mit gezielten Programmen das Wissen der Kleinbauern über die Ursachen und Folgen des Klimawandels und über Maßnahmen zur Anpassung und Schadensminimierung zu erweitern.

Die dritte Studie ist eine Auseinandersetzung mit der verfügbaren Forschungsliteratur zum Thema Anpassung an den Klimawandel im Kontext von kleinbäuerlichen Betrieben und widmet sich insbesondere den theoretischen Grundlagen, den methodischen Ansätzen und den Forschungsergebnissen. Die wachsende Anzahl von Studien zur Anpassung ermöglicht ein vertieftes Verständnis der Potenziale der Anpassung und der damit verbundenen Kosten, der Entscheidungsprozesse auf betrieblicher Ebene, und des Zusammenhangs von Entwicklungsplanung und Strategien zur Armutsbekämpfung. Gleichwohl besteht weiterer Forschungsbedarf, so sollten etwa die theoretischen Grundlagen erweitert werden, um zusätzliche anpassungsrelevante Einflussfaktoren (etwa kognitive Faktoren, psychologische Variablen, Risikowahrnehmung und Risikoerfahrung) berücksichtigen zu können. Um dem Problem knapper Daten zu begegnen, sollten zudem Methoden entwickelt werden, die auch bei begrenzter Datengrundlage robuste Ergebnisse liefern.

Die vierte Studie entwirft ein Modell, um den Einfluss von Risikoerfahrungen und sonstigen ressourcen- und wissensbezogenen Variablen auf die Anpassungsentscheidungen der Bauern zu analysieren. Die Studie basiert auf einem aus der Theorie der Schutzmotivation abgeleiteten Konzept zur Wahrnehmung und Abschätzung von Risiken und dessen Zusammenhang mit dem Entscheidungsprozess zu Anpassungsmaßnahmen. Laut Forschungshypothese würden Faktoren wie Risikoerfahrung und Risikowahrnehmung die Anpassungsentscheidungen von Kleinbauern beeinflussen. Mithin sollte die Bereitschaft zu derartigen Maßnahmen steigen, wenn Risikoerfahrung und Risikowahrnehmung nahelegen, dass klimabedingte Risiken tatsächlich auftreten. Die ökonometrischen Analysen der Studie konnten zeigen, dass gewisse Formen der Risikoerfahrung wie starke Ertragsausfälle die Anpassungsentscheidungen der Kleinbauern entscheidend beeinflussen. Einen weiteren wesentlichen Einfluss stellen Variablen sozioökonomischer (Geschlecht, Ausbildung, Haushaltsgröße), institutioneller (Landwirtschaftsberatung) und agrarökologischer Art dar. Nicht zuletzt bietet die Risikowahrnehmung der Landwirte der Politik einen wirksamen Ansatzpunkt, da sie durch entsprechende Kommunikationsstrategien beeinflusst werden kann.

Zusammenfassend zeigen die Studien, dass die genaue Kenntnis der örtlichen Begebenheiten dabei hilft, die Folgen des Klimawandels besser zu verstehen. Es sollten mithin weitere Forschungen zur Agrarökologie, den sozioökonomischen Bedingungen und den Produktionstätigkeiten stattfinden. Die Wahrnehmung des Klimawandels und die Anpassungsentscheidungen werden wesentlich von orts- und haushaltsspezifischen Faktoren bestimmt. Die Studienergebnisse erweisen die Notwendigkeit, insbesondere den Kleinbauern Wissen zum Klimawandel zu vermitteln, da diese die klimatischen Veränderungen bisher nur unzureichend wahrnehmen. Hierfür müssen ortsspezifische Voraussetzungen ebenso berücksichtigt werden wie demografische Faktoren, etwa Ausbildungsniveau, Geschlecht und Alter der Kleinbauern. Weiterhin kann geschlussfolgert werden, dass ohne angemessene Gegenmaßnahmen die Existenz vieler Kleinbauern insbesondere in den wärmeren Regionen Äthiopiens bedroht sein wird. Deshalb sollten die nötigen landwirtschaftlichen Maßnahmen sich zunächst auf die wärmeren Regionen konzentrieren. Schließlich sollten die Entscheidungsträger mithilfe geeigneter Kommunikationsstrategien eindeutige Botschaften zu den zukünftigen

Risiken des Klimawandels formulieren, um Kleinbauern zum Ergreifen von Anpassungsmaßnahmen zu motivieren.

1. Introduction

Climate change can affect crop productivity through the direct effects of temperature, rainfall and CO_2 on crop physiological activities and phenological development (Lobell and Gourdji 2012) and indirectly by altering pest incidence and plant-pest interactions (Juroszek and Tiedemann 2013). These direct and indirect effects may reduce crop yield or significantly alter land suitability for crop production. Also, livestock production can be influenced through the direct effects of changing temperature on animals, and indirectly through the potential impact of temperature, rainfall change and CO_2 on forage growth (Nardone et al. 2010). Additionally, though most of the climate change impact discussions have been focusing on productivity, climate change causes wide-ranging impacts besides decreasing productivity. For example, increasing CO_2 concentration may reduce the nutritional quality of some foods (Myers et al. 2014) and food-borne disease pressure may increase due to changes in the conditions for food safety, affecting food utilization (Schmidhuber and Tubiello 2007).

As the global food production is affected by climate change, feeding the growing world population may become a significant challenge (Schmidhuber and Tubiello 2007; Nelson et al. 2009). For instance, it is projected that global food production increase of up to 60% is needed to meet the increasing food demands of the growing world population by 2050 (Alexandratos and Bruinsma 2012). How to achieve this in the face of climate change is a major challenge. The challenge becomes even greater when considering regional and national level food security, due to potential regional differences of climate change impact; as some regions will be more affected than others (Parry et al. 2004). For instance, small changes in temperature may result in significant food production loss in warm regions that already have temperature near to physiological maxima than in colder regions (Gornall et al. 2010). The fact that most of the low-income countries that highly rely on agriculture are located in warm regions of the world exacerbates the risks of climate change for these areas. As a result, food insecurity and risk of hunger may likely continue to be challenging issues in these regions due to climate change (Nelson et al. 2009).

Adaptation and mitigation actions are suggested as potential strategies to reduce the impacts of climate change in agriculture. Mitigation refers to actions that aim to minimize emission concentrations either by reducing emission or by enhancing the sinks of greenhouse gas, so as to limit the rate and magnitude of warming (IPCC 2014). Whereas, adaptation involves to any action or "*adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities*" (IPCC 2007b). Adaptation is a strategy to moderate or cope with climate change that is not avoided by mitigation actions. Because of past emissions and inertia in the physical climate system, some degree of warming is inevitable even in the most optimistic emission reduction measures (Gornall et al. 2010), making adaptation a necessity. Adaptation alone, however, will not be sufficient to prevent impacts of future warming, and mitigation measures too must be taken to stabilize the climate and prevent irreversible effects.

Because of the seriousness and evident risks of climate change, there have been numerous scientific research efforts in the past to improve knowledge of the climate change and its' impact, and to provide evidence on the potential solutions to minimize the impact. Adaptation and mitigation planning requires sound scientific research and evidence on how climate will change in the future, what extent of damage is expected from climate change, what adaptation and mitigation options exist and the opportunities and barriers to adaptation and mitigation responses.

For example, in many smallholder systems agriculture is rain-fed. Therefore, it is paramount to understand what changes are expected in the future in terms of the amount and distribution of rainfall. What will happen if farmers continue to use their crop calendar and farming practices under climate change is a critical question. If current practices are not suitable for the changing climate, what options do exist? The alternatives can range from adjusting the crop calendar, to changes in agricultural input use and to switching to other crop species. However, farmers may continue to use the old practices despite the damages from climate change due to for example unaware of the potential adaptation options or lack of financial capacity or lack of understanding the risk. Furthermore, given the subsistence nature of smallholder farming, it is relevant to understand the food security impacts of the choice of farm adaptation strategies.

A substantial number of past and current studies are contributing for the climate change literature. For instance, the climate-modelling literature has been investigating the climate system to understand the response of the climate system to increasing greenhouse gas concentration and developing general circulation models (GCMs). The GCMs project future climate based on projected changes in greenhouse gas concentration and sulphate aerosol from a set of emission scenarios or representative concentration pathways (IPCC 2007a). The GCMs combined with regional climate models and downscaling techniques produce useful future climate information to be used for agricultural impact assessment research. A lot of progress have been made with regard to the understanding of the climate system and projecting the future climate; however climate projections are still somehow subjected to uncertainties. Uncertainties on how much greenhouse gas will rise; models' differences in climate sensitivity or difference in the way certain processes and feedbacks are modelled and parametrized; and internal climate variability (Deser et al. 2012) are sources of climate change projection uncertainties. The uncertainties in climate projections present critical implications for impact assessment, and thereof adaptation and mitigation planning; however, the GCMs are yet the most advanced available tools to model climate change.

The current study is motivated by the many climate change related problems smallholder farmers in developing countries are facing and the need for appropriate and effective policy interventions. The unique characteristic of smallholder farms in terms of heterogeneity in production systems and the wide range of agro-ecology that farms operate, even within the same country, present a particular challenge for climate change impact and adaptation research. The significance of agriculture for many developing countries and their limited capacity to respond to climate change risks add another element to the concern. Despite the serious risk climate change poses, how climate change will affect smallholders agriculture is not adequately investigated to provide information relevant for policy makers to formulate context specific and effective response strategies. For example, it is not well known which crops will be the most affected, or which agro-ecological regions need priority in terms of interventions. Policy makers also need to know which households to target for intervention actions. A large portion of the past studies has been carried out to assess impact at a large scale such as regional or national levels. Although large scale studies produce relevant information for high-level decision making, aggregation hides significant local level differences (Fernández and Blanco 2015) and do not sufficiently represent local differences. If policy makers rely on aggregated information, it may lead to either under estimating or overestimating the impact, which in turn results in inappropriate intervention measures.

Smallholders’ climate change impact assessment literature often lacks to fully address local agro-ecology, production systems, and socio-economic specifications. Studies that take into account location-specific information play an important role to reduce the uncertainty concerning to the implications of climate change on the local food production, which has major contribution for food security in developing countries. Such knowledge will ultimately help to develop policy measures and strategies that are needed to reduce the risks of climate change for farmers in developing countries.

The current research builds upon previously formulated concepts and theories on issues surrounding climate change and agriculture including productivity changes due to change in climate variables and, how agricultural producers perceive and respond to these changes. The study focuses on the agriculture of Ethiopia, one of the countries most vulnerable to climate change. Changes in temperature and rainfall have been observed throughout the country (Tadege 2007) and future climate change projections also indicate warming of the country and changes in rainfall distribution and pattern (Conway and Schipper 2011). Agriculture has significant contribution to the economy similar to many other developing countries. The common production system is one prevailing in many developing countries constrained by inputs, infrastructure, and markets. A range of agro-ecology characterizes the country. This study focuses on cereal based production systems located in two agro-ecologies found in a major agricultural production region. Data from household survey, long-term yield data from statistical reports, data from local agricultural offices, historical weather data and projected climate data are used for the studies included in this dissertation. Towards the achievement of the different objectives (described in chapter 1.1), this study uses a set of approaches and methods including econometric modelling, economic simulation methods, crop yield modelling, and long-term weather data analysis.

The dissertation approaches the topic of climate change on smallholder agriculture addressing three important dimensions: i.e., impact on food production and farm income, perception, and adaptation actions. This holistic approach addressing multiple issues of climate change offers a comprehensive picture of the problem and provides insights into policy measures needed to build smallholders resilience to climate change. The findings from the studies incorporated in this dissertation indicate that climate change threatens many smallholder farms and thus it is important to improve farmers understanding of climate change perception by providing accurate information on climate change, and to enhance farm level adaptation by communicating the risk of climate change and improving the capacities to adapt.

1.1 Research objectives

This research aims to contribute to advancing the literature on the implications of climate change, associated farmers perceptions, and behavioral changes in terms of adaptation in the context of smallholder farmers. The research targets at informing policy makers and interventions that attempt to reduce smallholder farmers' risk of climate change and food insecurity. Specifically, the main objectives of the study are:

I. to assess the economic implications of future climate change on farms under various socio-economic development scenarios.

II. to model the impacts of various climate change scenarios on major cereal crops in the study areas.

III. to assess whether farmers’ climate change perceptions relate to demographic, economic, knowledge, agro-ecological and institutional variables.

IV. to review and synthesize the methodological approaches, empirical findings and research gaps of the climate change adaptation literature in the context of smallholder agriculture.

V. to assess how the climate change adaptation actions of farmers relates to their risk experience, resource and information related variables.

1.2 Organization of the dissertation

The dissertation is divided in to six chapters (including the introduction presented in this first chapter). The first chapter introduces the research topic and presents the objective of the dissertation. Chapter two of this dissertation provides state of the art reviews of climate change impact assessment studies and approaches, determinants of climate change perception and adaptation. The third chapter describes the study areas, the datasets used in this dissertation and the methodological approaches of the various studies included in the dissertation. The fourth chapter provides general overview of the results and discusses important results of the dissertation. The major conclusions and policy implications are presented in chapter five. Finally, chapter six presents future research outlook.

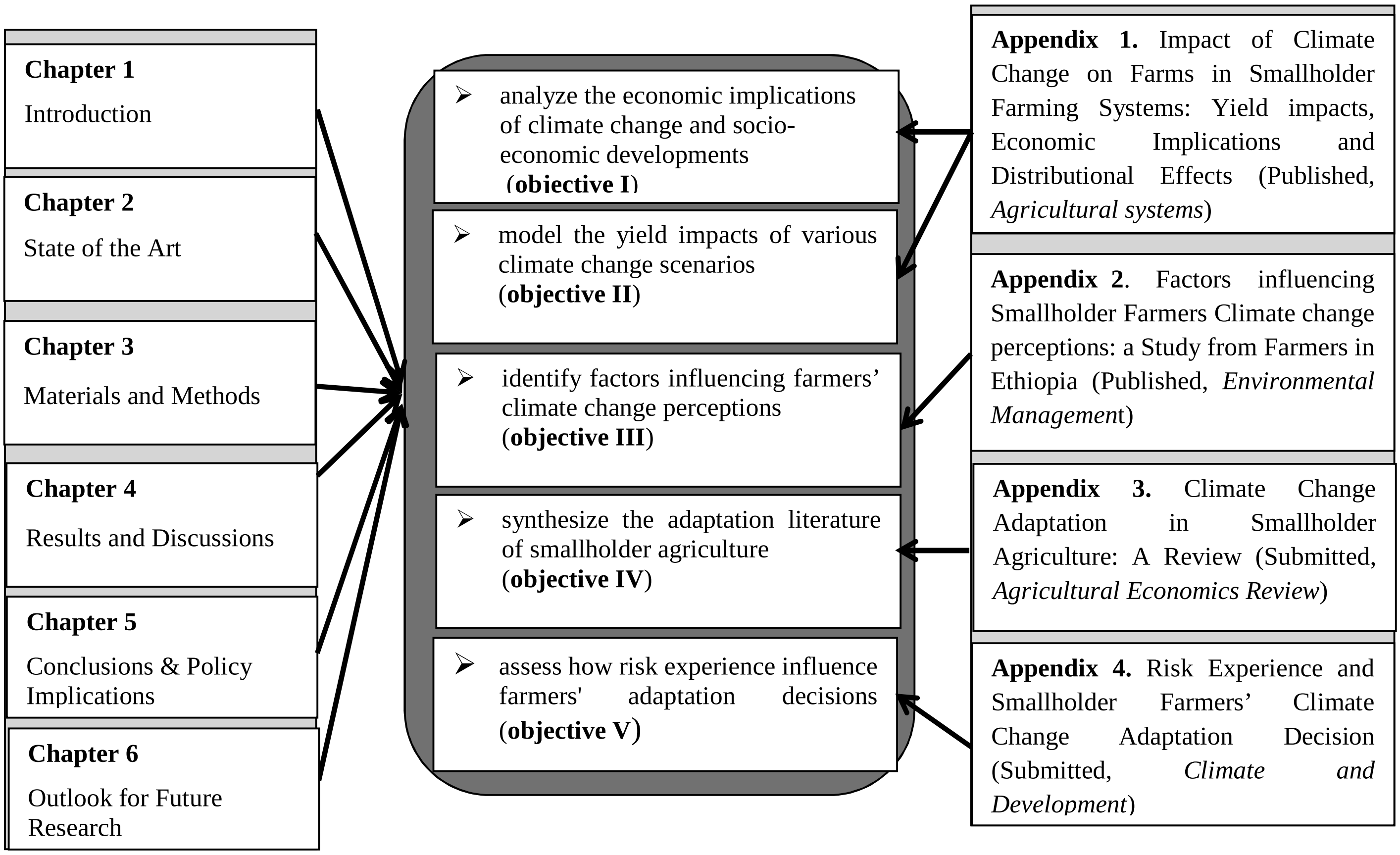

Fig. 1 Overview of the dissertation content

1.3 Publication and submission records, and author contributions

The present work is submitted as cumulative thesis and is based on the following publications and submissions

1. Impact of climate change on farms in smallholder farming systems: yield impacts, economic implications and distributional effects (Agricultural Systems, 152 pp. 58-66, Published)

Lemlem Teklegiorgis Habtemariam, Getachew Abate Kassa and Markus Gandorfer

This study assessed the expected impact of climate change in the study areas. The approach was by modeling the expected yield changes in crop production due to climatic change, and combining with future local socio-economic development scenarios. The study modeled yield changes of major cereal crops in the study areas due to climate change. Two alternative plausible future local socio-economic development scenarios were included in the analysis. The study used an economic simulation model to simulate the economic implications of yield changes and socio-economic development scenarios. The findings showed the distributional impact of climate change attributed to difference in agro-ecology, production activity, farm characteristics and socio-economic development scenarios.

Contributions: Lemlem T. Habtemariam collected all the necessary data, developed the methodological approach, conducted all the analysis, wrote the complete draft manuscript and revised the analysis and manuscript after discussing with co-authors and peer review process. Co-authors discussed and contributed throughout the process with ideas to include in the analysis and the contents of the manuscript; they revised the manuscript before and after peer the review process.

2. Factors Influencing Smallholder Farmers' Climate Change Perceptions: A study from farmers in Ethiopia (Environmental Management, 58(2) pp. 343-348, Published)

Lemlem Teklegiorgis Habtemariam, Markus Gandorfer, Getachew Abate Kassa and Alois Heissenhuber

The study assessed the climate change perception of farmers, analyzed trends in the local long term climatic changes and identified the various demographic, economic, agro-ecological and knowledge variables that are related with different categories of farmers climate change perception. Trend analysis was made on rainfall and temperature variables in the two study areas. Two econometric models were used (i.e., simple probit and recursive bivariate probit model) to assess perception related variables. In the recursive bivariate probit model the issue of endogeneity in one of the explanatory variables was addressed by including an instrumental variable. By modeling different categories of climate change perception separately the study showed how the various factors are related with the different categories of perception.

Contributions: Lemlem T. Habtemariam developed a questionnaire, conducted a survey together with field assistants, obtained secondary data, conducted the econometric modelling and climate data analysis, wrote the complete draft manuscript and revised the manuscript after discussing with co-authors and after peer review process. Co-authors contributed throughout the whole process with ideas to be included in the survey and modelling, discussed results, they revised the manuscript before and after peer review process.

3. Risk experience and smallholder farmers' climate change adaptation decision (Climate and Development, Submitted)

   Lemlem Teklegiorgis Habtemariam, Markus Gandorfer and Getachew Abate Kassa

The focus of this study was the adaptation decision of farmers. The study examined the role of risk experience in adaptation decision, which had not been well addressed in the literature of climate change adaptation. Whether perceived risk experience in terms of agricultural production shocks and yield reduction influence farmers' decisions to adapt was the main emphasis. The multivariate endogenous probit model was used controlling for potential endogeneity of perceived risk experiences to adaptation decision. The results suggested that the role of risk experience in adaptation decision of farmers' depends on the magnitude of damage/risk the experience has caused.

Contributions: Lemlem T. Habtemariam conducted the modeling, wrote the complete draft manuscript and revised the analysis and manuscript after discussing with co-authors. Co-authors contributed throughout the process with ideas to include in the analysis; they revised the manuscript.

4. Climate Change Adaptation in Smallholder Agriculture: A review (Agricultural Economics Review, Submitted)
   Lemlem T. Habtemariam, Getachew Abate Kassa, Markus Gandorfer and Alois Heißenhuber

The focus of this study was the climate change adaptation literature of the smallholders system. The study synthesized the key research issues, methodological approaches and the main findings of the climate change adaptation literature that focuses on smallholder agriculture. The synthesis covered a vast array of literature including from socio.-economic and biophysical disciplines. The synthesis showed the conceptual and methodological complexity and specificities needed to model the adaptation decision-making process of farmers and to assess the impacts of adaptation. At the end, the study showed the main research gap in terms of thematic focus, methodological approach, innovation adaptation types and temporal aspects of adaptation.

Contributions: Lemlem T. Habtemariam reviewed the literature, wrote the complete draft manuscript and revised the manuscript after discussing with co-authors. Co-authors contributed throughout the process with ideas to include in the content of the manuscript.

2. State of the Art

2.1 Climate change and its economic implications

The economic decisions and choices made by farmers under climate change to improve productivity and their well-being have consequences on their farming success but also have major impact on the achievement of sustainable food systems both locally and globally. Appropriate agricultural policy strategies and instruments have long been considered to have profound impacts in providing support to improve farming productivity and to aid farmers' decisions under risk and uncertainty. With this regard, impact assessment methods that quantify the economic and other implications of changes have been useful to understand the extent of damage a change or a risk would bring on farms and the society.

An increasing amount of climate change impact assessment literature exists regarding the extent of damage climate change will bring on agriculture, food security, and rural livelihood. The available studies have covered different geographical regions, economies, production systems, and time-periods; as climate change is expected to have different implications within these contexts. For example, some studies have assessed the impact of climate change on agriculture of the developed nations (e.g., Schlenker and Roberts 2009; Lippert et al. 2009). Others have focused on low income countries agriculture (e.g., Mendelsohn 2008; Morton 2007a; Schlenker and Lobell 2010) and some others focused the global level impact (e.g., Parry et al. 2004; Rosenzweig and Parry, 1994; Fischer et al. 2005). As the extent of climate change will vary over time, these impact studies have also addressed range of time-periods from near-term effects to the end of century effects.

A wide variety of methods and approaches have been applied in previous studies to assess climate change impact with major contribution from agronomy and economic disciplines (Fischer et al. 2005; Schlenker and Lobell 2010; Jones and Thornton 2003; Nelson et al. 2009; Nelson et al. 2010). The different methodological and modelling approaches of impact assessment have advantages and disadvantages that have implications for the result (Mendelsohn et al. 1994). For example, whether the impact assessment methodological approach takes into consideration the effects of carbon fertilization, or whether potential farm adaptation responses are accounted for, or whether potential future socio-economic changes are considered all have implications (Mendelsohn and Dinar 2009). Furthermore, the methodological approaches and assumptions made about the future climate and socio-economic settings are relevant factors that influence the uncertainty in the level of impact (Mendelsohn et al. 1994).

Among the most commonly applied methods to assess the impact of climate change on agriculture includes process-based crop models (Thornton et al. 2009; Abraha and Savage 2006), statistical models (Lobell and Burke 2010) and the Ricardian approach (Mishra and Sahu 2014; Deressa et al. 2009; Wang et al. 2009; Mendelsohn et al. 1994). Process-based crop-yield simulation has good potential to predict the direct impact of climate change on yield provided the minimum standards for data selection and quality are met. The input requirements of process-based modeling include data on rainfall, temperature, solar radiation, soil and management practices. For yield prediction, the different physiological mechanisms of crop processes are represented mathematically in the model in which key parameters are established from laboratory and field experiment data (Roberts et al. 2017). An intensive data requirement is among its disadvantage, and its sole focus on yield impact limits its use in economic studies.

The statistical yield modelling provides an alternative when detailed field data is lacking to calibrate process-based crop models (Lobell and Burke 2010). In statistical models, regression is used to establish a link between historical crop yield data and weather data, and the historical association is used to make prediction about yield under climate change (Roberts et al. 2017). However, the problem of collinearity among predictor variables such as between rainfall and temperature variables is among the major concerns in the use of the statistical approach (Lobell and Burke 2010).

The Ricardian method of climate change impact analysis, first introduced by Mendelsohn et al. (1994) has the advantage to measure economic impact by examining the relationship between land values or farm revenue, and a set of climatic and other variables from cross sectional data. Mendelsohn et al. (1994) argues that modelling climate change impact without controlling for actual farmers adaptation (as it is done in processed-based approaches) over estimates the impact of climate change. The Ricardian method is developed to address this limitation of process-based models. However, the Ricardian approach has also come with its own shortcomings failing to account for important variables. For example, it has been found crucial to account for CO_2 fertilization effect, future socio-economic changes and crop agronomic differences to assess the impact of climate change; which the Ricardian approaches lacks to address. The Ricardian technique in its original form and modified versions have been widely used by many authors to assess the impact of climate change using national level cross sectional data in many African and Asian countries. Among them are a number of World Bank research working papers (e.g., Maddison et al. 2007; Nhemachena and Mano 2007; Kabubo-Mariara and Karanja 2007).

With regarding to the findings , past studies suggest that the nature and extent of climate change impact is location and crop specific, and the time period into consideration has a significant role

(Nelson et al. 2014). It is indicated that developing countries' agriculture will be the most affected (Mendelsohn 2008) due to their geographical location and low adaptive capacity. Location is important because the nature of climate change is not uniform across the globe. Moreover, it is suggested that local peculiarities in terms of production system, agro-ecology and socio-economic characteristic have significant implications for impact. Additionally, the climate change adaptation capacity of agricultural systems varies from place to place depending on the constraints and opportunities available whether it be in terms of natural resource or socio-economic and institutional capacity. The impact of climate change is expected to increase over time, especially given the rather slow attention the international community has given to mitigate climate change. The physiological requirements of crops are not identical and hence so are their sensitivity to climate change; therefore, impact is found to vary among crop. The impact assessment literature have not yet adequately addressed heterogeneity in agricultural systems to understand the differential impacts of climate change that may arise from difference in farms' physical environment, production activity and other household characteristics.

2.2 Climate change perception

Economic and psychology theories and analysis provide useful insights about farmers' decision-making and their attitude and perception towards a risk. Perception about climate change is important, as it is a pre-condition for actions against climate change (Weber 2010). Individuals' willingness to take measures against climate change whether it be through adaptation or mitigation depends on how they perceive climate change and its risks.

The climate change perception literature has been dominated by studies that investigate the climate change perception of developed countries public (e.g., Brody et al. 2007; Lorenzoni et al. 2007; Ratter et al. 2012); developed countries farmers (e.g., Arbuckle et al. 2013; Eggers et al.

2015; Niles et al. 2013; Prokopy et al. 2015); and smallholder farmers (e.g., Roco et al. 2014, Deressa et al. 2011, Silvestri et al. 2012). The focus of the studies that investigated the perception of farmers in developed nation have been into assessing farmers' perception on the occurrence, causes, and risks of climate change (Habtemariam et al. 2016). The studies from smallholder farmers in low-income countries have focused to investigate farmers' perception on long-term local climatic changes and perceived risks. Nonetheless, despite existing studies that provide descriptive statistics on smallholder farmers' climate change perceptions in developing regions, attempts with regard to the identification and analysis of factors affecting their perception are relatively few.

The perception of climate change can be influenced by many factors. First, it is not always easy to recognize long-term changes in climate change. The natural day to day variability in the weather affects our ability to recognize long term changes (Akerlof et al. 2013). People may fail to perceive climate change because they do not have the information about the change or they may lack the cognitive skill to recognize the change in long-term weather condition. Second, a number of socio-economic, ideological, environmental and cognitive factors might affect our perception about climate change. Because the implications of climate change is not uniform across socio-economic groups, political ideologies and environmental conditions (Kahan et al. 2011; Weber 2010).

Also, the focus of previous studies have been investigating farmers perception of past climate change. Farmers' perception or anticipation of the future climate change is not well investigated in previous studies. Furthermore, the findings of previous studies suggest, though some common factors exist, the factors that affect farmers perception might be location specific in some cases. It is therefore paramount to consider local context when modeling the factors that influence farmers' climate change perception.

2.3 Adaptation in smallholder agriculture

Adaptation emerged as an important subject of research and policy discourse when adaptation become increasingly regarded as one of the main strategies to deal with the climate change (Burton et al. 2011). Adaptation refers to adjustment made to minimize the risks of actual or expected climate change (IPCC 2007b). In agriculture, these adjustments include changes made in production activities, input use or agronomic managements.

The climate change adaptation literature is dominantly informed by socio-economic (Deressa et al. 2009; Jain et al. 2015), biophysical (Singh et al. 2014), adaptation cost analysis (World Bank 2010a; UNFCCC 2007), and policy and development related studies (Ayers et al. 2014). The socio-economic research domain recognizes that farmers' adaptation decisions are determined by their socio-economic conditions and experiences. Farmers' adaptation decisions are therefore often conceptualized within these contexts. The studies in the socio-economic domain aimed at informing adaptation policy and the design of strategies that facilitate uptake of adaptation actions by studying variables with most significant association to farm level adaptation decisions (e.d., Burton et al. 2011; García de Jalón et al. 2016). Over all, the literature on climate change adaptation decisions of farmers suggest local particularities in terms of the variables that associate with adaptation decision.

The studies from biophysical research field have mainly focused on identifying and evaluating the potential of adaptation measures to reduce the impact of climate change on crop productivity (e.g., Singh et al. 2014; Kassie et al. 2015) and cropping systems (e.g., Waha et al. 2013). The studies have identified many promising farm adaptation measures. The identified adaptation measures included adaptation through changing the plating date and input use.

The adaptation cost research has sought to estimate and understand the magnitude of economic costs to finance adaptation (e.g., World Bank 2010). The main elements of the climate change adaptation and development research has been about the processes and options to integrate climate change adaptation into development policies and to reduce the factors that cause vulnerability (Ayers et al. 2014). The literature shows a gap in terms covering adaptation in the livestock sector, the role of off-farm policy adaptation, assessing transformative adaptation types, and the temporal aspect of adaptation.

2.4 Risk experience and adaptation decision

Studies have been establishing a link between farmers' adaptation decisions and a range of socio-economic, biophysical and institutional determinants (e.g., Charles et al. 2014; Deressa et al. 2011; Jain et al. 2015). These factors and farmers' adaptation decisions have been linked in terms of determining access to resource and information required for adaptation. There have been evidence that suggest risk experience variables may also relate to climate change adaptation and mitigation behaviors (Grothmann and Patt 2005; Spence et al. 2011), and influence climate change adaptation and mitigation decisions by affecting risk perception (Weber 2006). Grothmann and Patt (2005) explain that climate change risk experience reduces the uncertainty associated with the occurrence and severity of climate change risk and maximizes risk perception. Higher risk perception is assumed to motivate for a response action. Weber (2006) shows that experience based risk perceptions have importance on decisions to take a response measure against a perceived risk.

Empirical studies are inconclusive. A study by Spence et al. (2011) found individuals who had direct flood experience to show higher mitigation behavior, while Whitmarsh (2008) shows that flood victims differ very little from others in their climate change response, and Tucker et al. (2010) show coffee farmers who perceived extreme weather to be slightly less likely to make adaptive changes.

Many of the previous studies on adaptation decision of stallholders have focused into understanding the link between adaptation decision and socio-economic variables. There have been limited studies that empirically assessed the role of risk experience and perception in the climate change adaptation decision of smallholder farmers.

Overall, the literature shows a gap in knowledge in terms of understanding the distributional impacts of climate change on smallholder systems, which may result from difference in agro-ecology, production activity and farm characteristics. The factors that influence the climate change perception of smallholder farmers are not well known. The role of risk experience in climate change adaptation decision of farmers is not well understood yet. Furthermore, the climate change adaptation literature of smallholder systems lacks a synthesis. To contribute to these research gaps this dissertation frames the studies included in the dissertation as presented below in Figure 2.

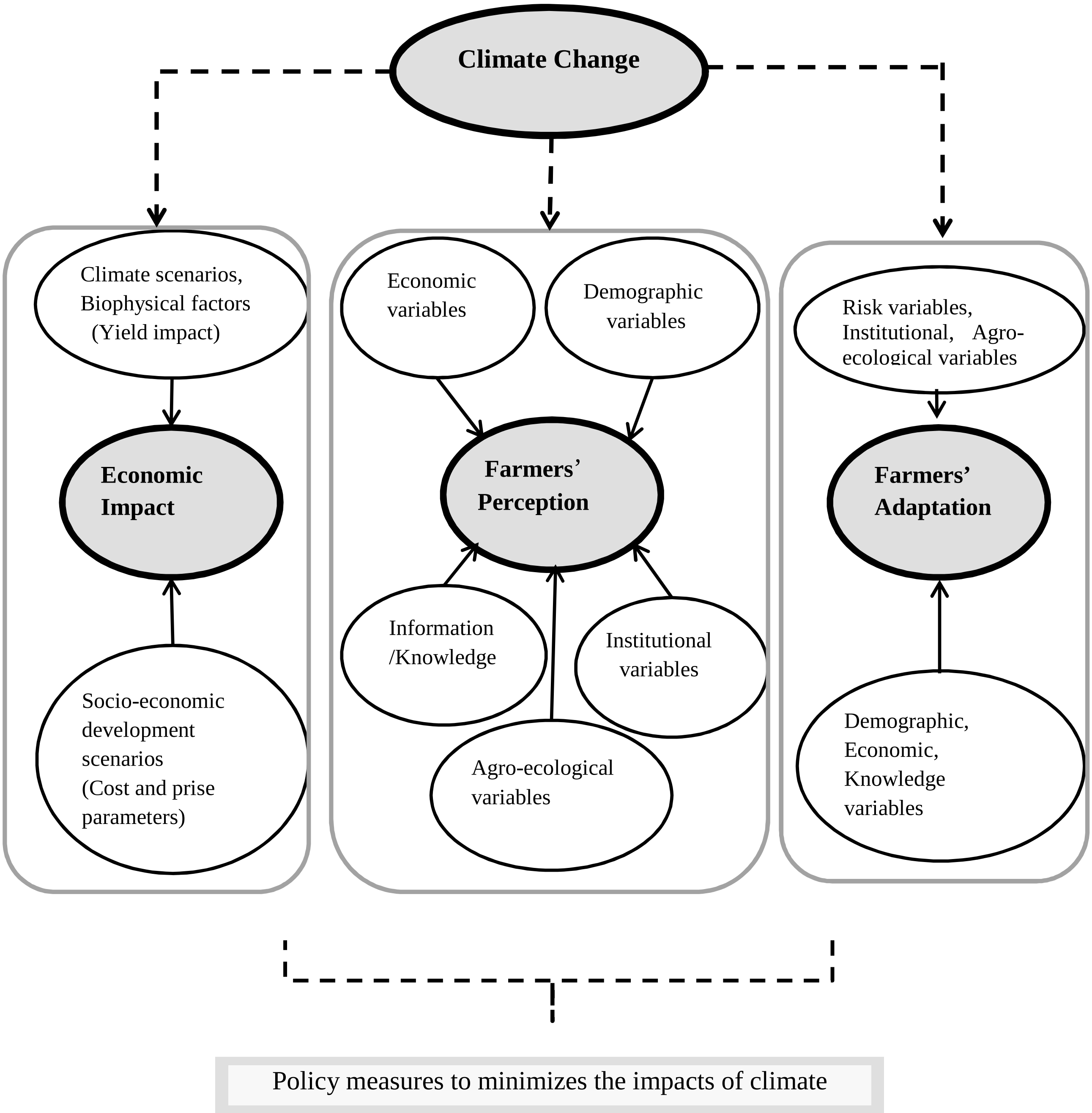

Fig. 2 Framework of the dissertation

3. Materials and Methods

3.1 Study area

The study is conducted in the Welmera and Dugda districts of Ethiopia (Figure 3). The Welmera district is located in central Ethiopia, covering an area of 809 km^2 at a mean altitude of about 2527 meters above sea level, and had a total population of 83,823 in 2007 (CSA 2010). The annual rainfall for the area varied between 729 mm and 1301 mm with a mean of 1038 mm during the past four decades. The average maximum and minimum temperatures during this period were about 22^0C and 6^0C, respectively. The Dugda district is located in the central rift valley area of Ethiopia, covering an area of 959.5 km^2 at a mean altitude of about 1700 meters above sea level, and had a total population of 144,910 in 2007 (CSA 2010). The annual rainfall of the area varies between 511 mm and 1130 mm with a mean of 771 mm over the past four decades. The mean maximum and minimum temperatures are 27^0C and 14^0C, respectively.

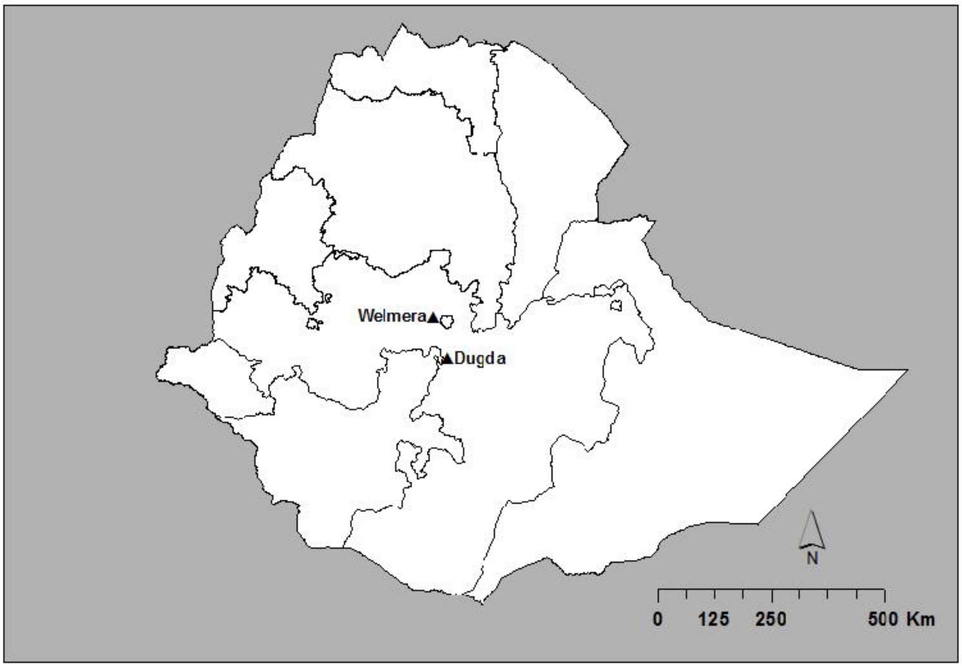

Fig. 3 Location of the study areas in Ethiopia

The farming system commonly practiced in the study areas is small-scale subsistence/ semi-subsistence mixed crop-livestock production system, which is also common in many major agricultural zones of Ethiopia. Farmers produce mostly for own consumption and generate only a small marketed surplus. The major crops grown in Welmera are cereals such as wheat, *tef*, and barley, while in Dugda food production is dominated by maize, *tef* and wheat. Unlike the Welmera district, where irrigated vegetable production is restricted to small areas in the backyards of households, farmers in some parts of Dugda produce irrigated vegetables such as tomato and onion, on a comparatively larger scale. In both areas cereal crop production is mainly rain-fed, access and use of technology and agricultural input is low, and the use of mechanized agriculture is rare. Vegetable production in Dugda uses relatively high farm inputs.

Livestock such as cattle and chicken are produced in small-scale and mainly for subsistence use of the products. Often the contribution of livestock such as cattle is mainly for the provision of draft power. Some households earn additional income from non-agricultural activities working outside of the farm as daily laborer or security guard in the nearby commercial farms. Few farmers earn income from small non-farm business of their own. The districts are not exceptional with respect to the widely recognized farming problems of Ethiopia, such as scarcity and expensive inputs, limited market and credit access, soil fertility problems, growing population pressures, and weak extension services.

3.2 Datasets

The main data sets used in this dissertation included household survey data, long term recorded meteorological data, future climate data and official historical yield statistics.

3.2.1 Household survey data

The survey data is from household-level interview conducted in the two districts. Respondents were randomly selected households from six peasant associations (the lowest administrative unit) located in the two districts. The survey data included 200 households from Welmera and 100 households from Dugda. The data was collected using a structured questionnaire comprising both open- and close-ended questions. The data covered a wide range of information including socio-economic background, production data on the various agricultural activities, and perception of climate change and adaptation measures. The survey data is used to analyze farmers' climate change perception, to assess the production activities and returns of farms under current climate, and to assess the adaptation actions of households.

3.2.2 Long-term local meteorological data

Long-term monthly rainfalls as well as minimum and maximum temperature records were obtained from the metrological agency of Ethiopia and a research institute. The data is from weather stations that are located within or close to the study districts. These include weather data from Holleta, Meki and Ziway weather stations. The available meteorological data covered the period 1969-2010 for Holleta, 1966-2010 for Meki and 1983-2010 for Ziway stations. The data is used to analyze local changes in temperature and rainfall.

3.2.3 Future climate data

Daily data on rainfall, maximum- and minimum temperature, and solar radiation required for the yield simulation process were obtained from the web version of the stochastic weather-generating tool MarkSimGCM (http://gisweb.ciat.cgiar.org/MarkSimGCM/). Two sets of climate data i.e., one for a baseline period and one for a future period were used. For the baseline period, daily weather data in each site was generated for 30 weather years. For the future period, daily weather data is generated for the period 2020-2049 for two representative concentration pathways (RCPs); the very low forcing level concentration pathway RCP 2.6, and the very high forcing level concentration pathway RCP 8.5 from an ensemble of 17 global circulation models.

3.2.4 Yield statistics and economic data

For validation purpose of the yield simulation, available local yield statistics was extracted from publicly available archives of the central statistical agency of Ethiopia. This includes historical yield data of wheat, maize, barley and *tef* in the period 1995-2009. Further data collected from the central statistical agency archives and district agricultural offices include average unit price of each crop and price of farm inputs representative of the study period and districts.

3.3 Methods

3.3.1 Analyzing the impact of climate and socio-economic changes

The impact assessment methodology chosen for this study uses a framework that allows incorporating the direct impact of projected climate change upon individual crop, the potential changes in future socio-economic settings, and assesses the economic implications of climate change. The conceptual foundation of the modelling approach assumes farmers produce multiple crops that have different sensitivity to climate change, and the future socio-economic setting would likely differ from current conditions. Additionally, the approach takes into consideration farm heterogeneity and agro-ecological elements, the two key issues in climate change impact studies, making it possible to examine the differential impacts of climate change across farms and agro-ecologies. The methodological approach is particularly useful to model smallholder farming systems similar to the one in our study area due to the peculiar characteristics of such systems in terms of complexity and heterogeneity in production and socio-economic features.

3.3.1.1 Assessing impact on yield

The direct impacts of future climate change on major cereal crops of the study areas were assessed through yield modelling approach. This was done by simulating yield under future climate scenarios and then comparing future simulated yield with current simulated yield to estimate percentage yield changes. The percentage yield change is then used to estimate future yield calculated from observed current farm yield. In this process, for the future period, yield simulation was done for the period 2020-2049 based on climate scenarios data for two representative concentration pathways (RCPs) (i.e., RCP2.6 and RCP8.5) from an ensemble of 17 global circulation models. The average yield of the 2020-2049 period was used to represent the yield for 2030. The simulated yield for the current period was represented by calculating the average yield of the 30 baseline weather years.

3.3.1.2 Assessing economic impacts

For the economic simulation of climate change impact, a change in socio-economic settings was to be considered. The study considered two plausible socio-economic scenarios, which provided parametric estimation of future crop price and cost of inputs. The socio-economic scenarios (presented in Table 1) were adopted from a previous study that developed the scenarios based on the concept of representative agricultural pathways for a country with comparable socio-economic and environmental conditions of Ethiopia. The scenarios represented two alternative economic development scenarios in the country.

Together with the future yield data, data on future crop prices and costs were used to calculate net returns of the various crop production activities. The net returns were calculated as total return minus variable costs of seed, fertilizers, and chemicals. Similarly, the returns of crop activities under the current climate was estimated using the production data collected during farm survey which includes information on yield, cost and price.

An economic simulation approach implemented in the TOA-MD model was then used to assess the impact of climate change on the population of farms in the study areas. The model simulates impact by comparing farm returns under current production system against production system with climate and socio-economic change.

Table 1 Socio-economic changes (expressed as percent of the baseline period (100%)) assumed in the study

	RAP1 (positive economic development)	RAP2 (low economic development)
Cereals price	130	100
Cereals cost	90	110
Farm size	120	80
Off-farm income	150	100

RAP= Representative Agricultural Pathway
Source: Adapted from Claessens et al 2012

3.3.2 Assessing local climatic changes and farmers' climate change perception

In this study, the changes in long-term local meteorological data were analyzed. An econometric modeling was applied to investigate the relation between farmers' perceived changes in the local climate and various factors that influence perception.

3.3.2.1 Changes in long-term local meteorological data

Maximum and minimum temperature records obtained from the weather stations were assessed for linear trends by regressing temperature data on time. The statistical significance of the trends were then determined by a t-test. For rainfall, rainfall anomalies of the main rainy season were calculated as a deviation from the mean of a reference period, which lies within the current normal climate period as defined by the World Meteorological Organization. The patterns of rainfall anomalies were assessed based on the number of years that have below average rainfall in the past decade. Additionally, a trend test was made on the total main season rainfall.

3.3.2.2 Factors influencing farmers climate change perception

Several factors may play a role to shape farmers climate change perception. Demographic, economic, knowledge, agro-ecological and institutional variables are among the main factors that may influence perception about climate change. These variables can affect perceptions on climate change by affecting- access to climate change information, information acquiring and retention capabilities, and judgments.

An econometric modelling approach was applied to investigate the association between a set of demographic, economic, climate knowledge, agro-ecological and other relevant variables and farmers' climate change perception. The model builds upon previous developed concepts and empirical findings on the association between climate change perception and potential influencing factors. Different perception variables were created to represent the different categories of climatic variables (i.e., temperature and rainfall). Additionally, the perception of past climate and anticipation of future climate were assessed separately.

The study used the following general functional relationship to identify factors that influence each perception category:

$$Perception_i = F_i(\ district_i,\ gender_i,\ age_i,\ education_i,\ agricultural\ sell_i,\ soil\ status_i,\ farm\ size_i,\ climate\ change_i,\ shocks_i,\ credit\ service_i)$$

In addition to the simple binary probit model, the study applied the simultaneous equation model of the recursive bivariate probit model. The recursive bivariate probit model was chosen to handle potential endogeneity issue in one of the explanatory variables. In this approach, the main outcome variable and the potential endogenous explanatory variables were modeled as a recursive bivariate probit model. The main outcome equation included all the exogenous covariates and the endogenous explanatory variable. The reduced form equation of the potentially endogenous regressor has included an instrumental variable. The two equations were estimated simultaneously by maximum likelihood method.

3.3.3 Assessing farmers' adaptation decision and risk experience

A random utility maximization framework was used to model farmers' adaptation decisions. In the framework, the farmer decides to take action if the expected utility gained from taking action is greater than the utility gained from not taking action.

The probability of taking action is expressed as a function of observed characteristics (X) in the latent variable model as follows:

$$A_i^* = \beta X_i + \varepsilon_i \qquad , \qquad A_i = \begin{cases} 1 & \text{if } A_i^* > 0 \\ 0 & \text{otherwise} \end{cases}$$

The explanatory variables included variables that represent risk experience and other socio-economic, farm characteristic and institutional factors that may affect farmers' climate change adaptation decisions. Risk experience was represented in the model in terms of farmers' perceived experience of crop yield reduction and production shock. In the model, the binary explanatory variables representing perceived risk experience were considered potentially endogenous to adaptation decision. As a result, endogenous multivariate probit analysis with recursive structure was applied to address for potential endogeneity of the two explanatory variables. The multivariate probit model was built from three binary equations in which one equation represented the structural equation of interest (adaptation decision model) and two reduced form equations for the potentially endogenous dummy variables as follows:

$$A_i^* = \beta' x_i + \gamma' \mathrm{Y_i} + \alpha' S_i + \varepsilon_1 \quad , \quad A_i = \begin{cases} 1 \; if \; A_i^* > 0 \\ 0 \; otherwise \end{cases}$$

Where x_i is the vector of exogenous covariates and, $\mathrm{Y_i}$ and S_i represents the endogenous explanatory variables, ε_1 is the error term, and β', γ' and α' are the set of unknown parameters corresponding to x_i , $\mathrm{Y_i}$ and S_i respectively.

$$\mathrm{Y_i^*} = \tau' x_i + \vartheta' S_i + \varepsilon_2 \quad , \quad \mathrm{Y_i} = \begin{cases} 1 \; if \; \mathrm{Y_i^*} > 0 \\ 0 \; otherwise \end{cases}$$

$$S_i^* = \delta' x_i + \varepsilon_3 \quad , \quad S_i = \begin{cases} 1 \; if \; S_i^* > 0 \\ 0 \; otherwise \end{cases}$$

The method of estimation was by simulated maximum likelihood methods using the Geweke-Hajivassiliou-Keane (GHK) simulator (Cappellari and Jenkins 2003).

4. Result and Discussion

The impact of future climate change on farm income and the perception and adaptation behavior of farmers have been studied in this dissertation. The studies aimed to contribute to knowledge gaps in the research topics of impacts of climate change, perception and adaptation in the context of the smallholder agriculture system. The unique conditions and features of smallholder farming systems i.e., the complexity and the heterogeneity in agro-ecology, production activity, farm and household characteristics, and the limited capacity to adapt to climate change; as well as data unavailability present a key methodological challenge and major interest in climate change impact and adaptation research.

4.1 The impact of climate and socio-economic changes

4.1.1 Impact on yield

The impact of climate change on yield was modelled separately for each major cereal crop in each study area. Climate scenarios from two concentration pathways together with the effects of rising CO_2 concentrations were considered in the modeling. The findings indicated that yield changes due to climate change vary between locations, among crops and climate scenarios. In the highland Welmera, the climate change scenarios predicted an overall positive yield impact. In the semi-arid Dugda, *tef* and wheat yield declined while maize yield increased under the climate change scenarios considered (results are presented in Figure 4).

The result suggested that regions that are already located in a warmer zone would face major yield losses in crops such as *tef* and wheat. In contrary, regions where cooler temperatures currently constrain crop production may benefit from future warmer temperature when rainfall is not constraining. The findings of the yield impact assessment which shows the divers impacts of climate change is broadly consistent with other studies from similar climatic environments that have also suggested the uneven impacts of climate change (Abreha et al. 2012; Evangelista et al. 2013; Jones and Thornton 2003; Kassie et al. 2015; Muluneh et al. 2014).

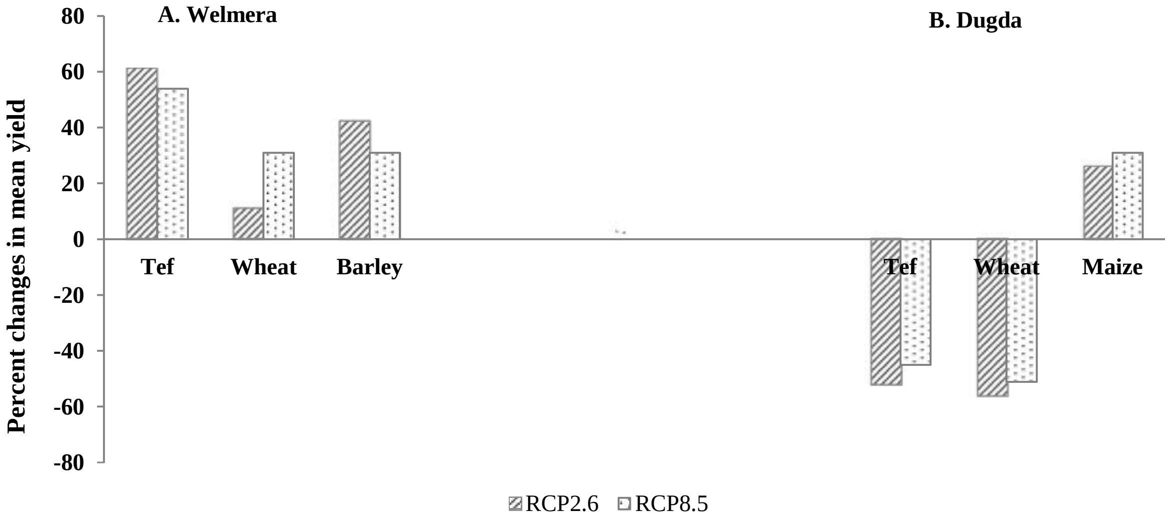

Fig. 4 Simulated percent changes in mean yield in 2030 relative to the baseline period in (A) Welmera and (B) Dugda districts under the two climate emission pathways (adopted from Habtemariam et al., 2017)

4.1.2 Economic impacts

The economic simulation model assessed the economic implications of yield changes due to climate change and changes in socio-economic settings. Figure 5 shows the proportion of farms that would be negatively affected by the changes and the associated loss per farm. The proportion of farms that are negatively impacted by climate change varied considerably between the agro-ecologies and socio-economic scenarios. The proportion of farms that are negatively affected by climate and socio-economic changes is much higher in the warmer Dugda than in Welmera in all the scenarios considered.

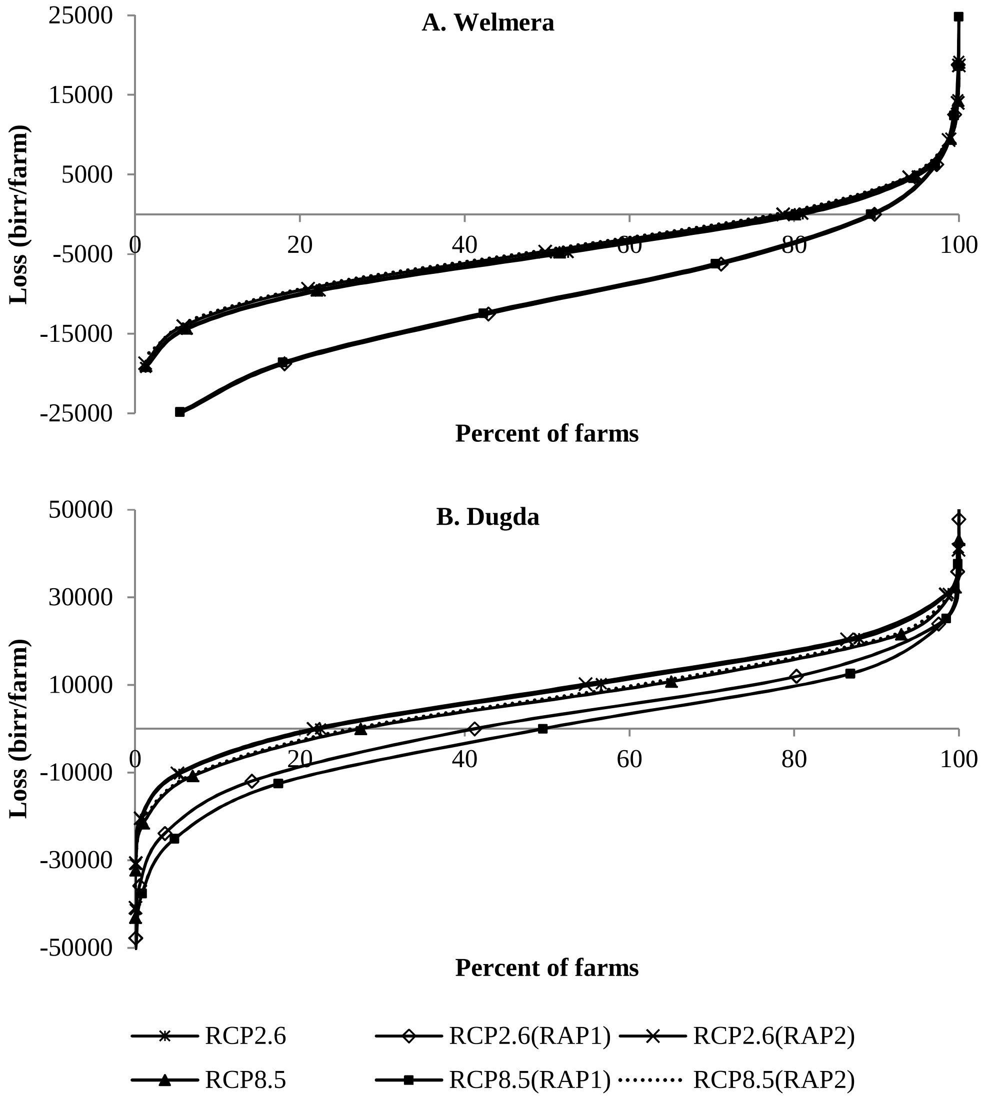

Fig. 5 The expected impact of climate and socio-economic changes on (A) Welmera & (B) Dugda farm populations by 2030 (adopted from Habtemariam et al., 2017)

RCP2.6= the impact of RCP2.6 climate change projection alone without consideration of socio-economic changes
RCP8.5= the impact of RCP8.5 climate change projection alone without consideration of socio-economic changes
RCP2.6 (RAP1) = the combined effects of RCP2.6 climate change projection and RAP1 socio-economic scenario
RCP8.5 (RAP1) = the combined effects of RCP8.5 climate change projection and RAP1 socio-economic scenario
RCP2.6 (RAP2) = the combined effects of RCP2.6 climate change projection and RAP2 socio-economic scenario
RCP8.5 (RAP2) = the combined effects of RCP2.6 climate change projection and RAP2 socio-economic scenario

Assessment on the impact of climate change has shown how future climate change and socio-economic developments would affect agriculture in the study areas. Assessment of the impacts of climate change is an important issue for climate change policy making at local, national and international level. The impact of climate change was diverse in which some crops and some areas will be severely affected than others. The diverse impact of climate change are attributed to spatial variability in terms of exposure to climate change, farm and household socio-economic characteristics, and farm production activities (for example in terms of which crops are grown). Literature also supports that these heterogeneities are relevant in impact assessment studies (Antle 2011; Antle et al. 2014). It is known that climate change will not manifest itself in the same way everywhere and thus geographically distinct patterns of physical exposure and sensitivity to climate change are observed. This spatial variability in exposure and sensitivity is one cause of unevenness in climate change impact. Also, the temperature and water requirements and the response to CO_2 increment of different crops are different. Furthermore, farms and systems do not have the same ability or potentials to respond or adapt to climate change. Various economic, technological and social factors can affect the ability to adapt and thus mediating the impact that climate change can exert on agriculture.

A variety of climate change impact modelling approaches are present in the literature with their own advantages and dis-advantages. Impact assessment approaches that focus only on an individual crop or those that use methods that estimate the average economic impacts of climate change on farms are not adequate to unravel the diverse impacts of climate change (Claessens et al. 2012). Heterogeneity in crop types and farm characteristics, and the role of agro-ecology need to be well addressed in climate change impact assessment studies. This can be done by modelling the yield of crops, which have different sensitivity to climate change, by comparing different agro-ecologies, and representing a population of farms instead of using aggregate methods. Impact assessment methodologies such as the TOA-MD developed to represent a population of heterogeneous farms are useful for this purpose.

Another important issue in climate change impact study is whether potential changes in future socio-economic settings are accounted in the impact assessment (Antle et al. 2014). There are many reasons why the future socio-economic conditions might be different from the present situation. One reason could be changes in economic growth. Various scenarios can be made in this regard, e.g., high economic growth vs low economic growth. In case of high economic growth characterized by infrastructure development and better agricultural policies, we may, for example expect more affordable inputs and better market structure. On the other hand, a low economic growth combined with a high population growth may result in expensive input prices and changes in farm structure and so forth, which in turn will affect the economic decisions and behaviors of farmers. Studies that simply compare a baseline and climate scenario without incorporating potential future socio-economic developments either may under- or overestimate climate change impact. It is obvious that explicitly incorporating all dimensions of future socio-economic changes is challenging, as there are many uncertainties regarding to the future economic, technological and the associated behavioral changes of farmers. This is particularly the case when assessing impact beyond the near term effects of climate change. However, certain aspects of future changes can be included in impact studies.

When assessing the economic implications of climate change, the impact assessment study also considered the role of two different economic growth scenarios, and the associated changes on agriculture related socio-economic conditions in determining the climate change impact. The study adopted the concept of representative agricultural pathways developed by the Agricultural Model Inter-comparison and Improvement Project (AgMIP). The representative agricultural pathways are story lines based on assumptions made about future changes such as population and income growth, and technological changes. The story lines are translated into model parameters to indicate expected socio-economic changes for example in farm and household size, prices and cost of production. The findings from the currents study indicated that the proportion of farms that are negatively impacted by climate change varied considerably between the two socio-economic scenarios. A positive economic growth scenario has reduced the proportion of negatively affected farms showing the role that socio-economic improvement can play in reducing vulnerability of farms in developing countries. Many previous impact assessment studies have not included plausible changes in the socio-economic environment when analyzing the impact of future climate change mainly due to lack of data about future changes. The lack to include future socio-economic changes in impact analysis is considered a limitation. There have been major efforts in recent years to develop plausible socio-economic scenarios for many regions around the globe. Future studies thus can benefit from the outputs of these modeling efforts.

The importance of using farm and site-specific production and climate data to reveal variabilities in climate change impact is one of the main findings of this study. The effects of climate change is a function of local climatic changes, local production activity and the capacity to adapt, and an analysis that investigate the impact of climate change at a broader scale would hide this relationship. It is known that lack of detailed production data representative of diverse agro-ecologies and farms is often a major constraint to perform an in depth yields impact analysis in many developing countries. Furthermore, the modelling of the yield of multiple crops is a computation-intensive work that consumes a lot of time and one that requires a large set of input data. However, modeling the yield of multiple crops is of particular relevance in agricultural system in which farms often simultaneously growing different crops. Given the risks climate change pose on agriculture, efforts should be made to obtain a better understanding of the effects of climate change as it is done in this study.

4.2 Farmers climate change perception

4.2.1 Long term climatic changes

The long-term meteorological data analysis showed an increasing trend of maximum and minimum temperatures in the study areas (Figure 6). The trend was found to be statistically significant in Ziway (both maximum and minimum temperatures) and in Holleta (only maximum temperature). The rainfall (main season) anomaly pattern showed below average rainfall for most years of the past decade, both at Holleta and Meki stations. Trend analysis of rainfall (main season) indicates a decreasing trend significant at $p < 0.1$ at both stations.

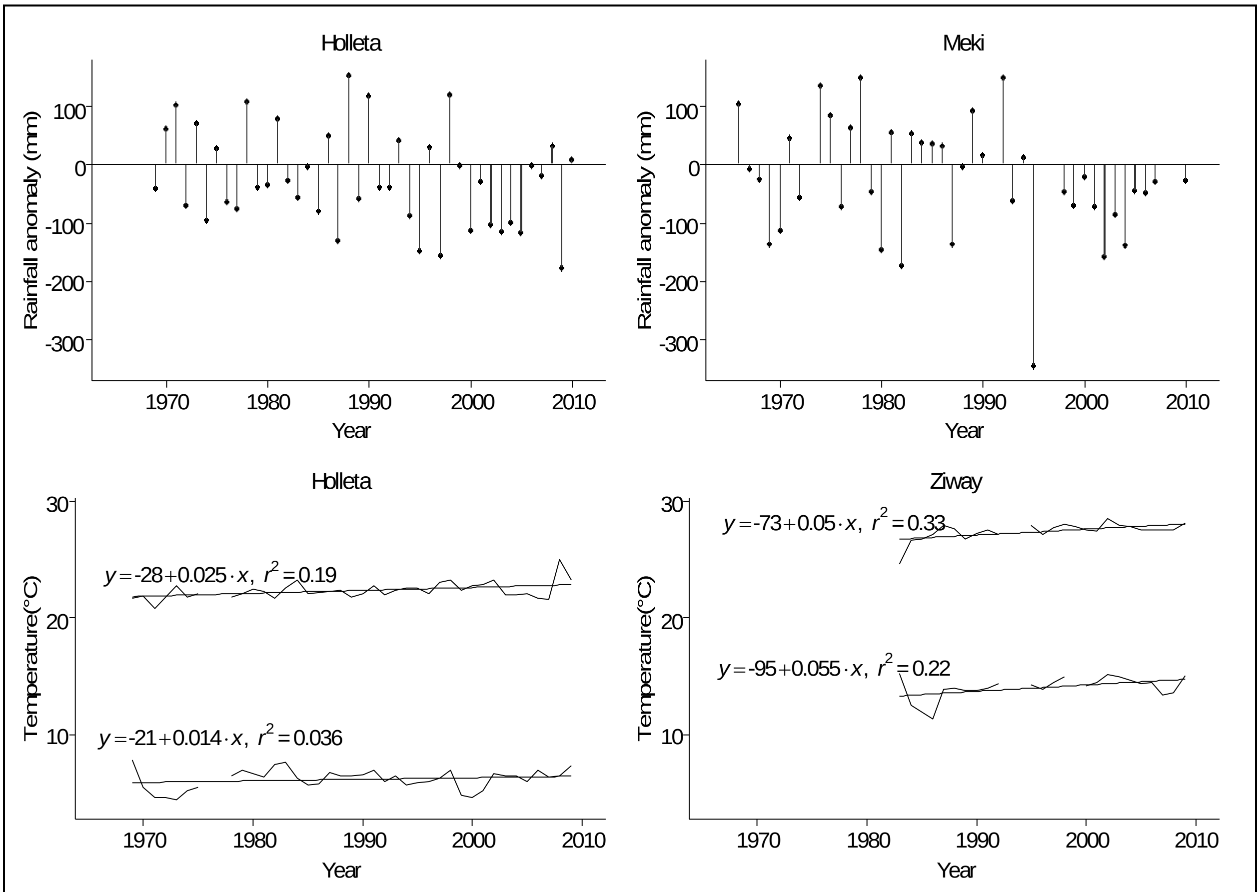

Fig. 6 'Kiremit' rainfall anomalies calculated based on 1969-1990 and 1966-1990 reference years for Holleta (2400 m.a.s.l) and Meki (1680 m.a.s.l) stations respectively; maximum and minimum temperature trends at Holleta and Ziway (1640 m.a.s.l) stations (adopted from Habtemariam et al., 2016)

m.a.s .l = meter above sea level

4.2.2 Factors influencing farmers climate change perception

An investigation into the various factors that influence farmers' climate change perception was conducted. Farmers' perception is found to be influenced by various factors representing the characteristics of the farmer, farm resources and agro-climatic variables (Table 2 and 3). The study showed that while some of the determinants of farmers climate change perception are specific to the particular climate variable in question (e.g., temperature vs. rainfall) or time-period (e.g., past climate change vs. future climate change), other determinants are more generic relating to all or most of the different categories of climate change perception. The difference in the natural patterns of temperature and rainfall variables i.e., the high annual variability of rainfall unlike to temperature is one reason why some explanatory variables were only important to perception of rainfall change.

Another potential cause is thought to be the difference in the implications of temperature and rainfall changes in agricultural production that has led changes in rainfall to be perceived differently as compared to changes in temperature. The perception of current and future climate events showed some difference in terms of the influencing factors. This is explained by the fact that the perception about future climatic condition refers to an event that involves some uncertainty in its occurrence, whereas past climate change is an event that has already happened. Therefore, farmers' individual characteristics may influence the perception of past and future events differently.

Climate change is a complex phenomenon; it is not always straightforward to notice long-term changes in climate, because often individuals may remember only recent events and develop misperception about the long-term changes. A combination of multiple factors is involved to shape the perception of climate change.

Table 2 Estimates of simple probit models (adopted from Habtemariam et al., 2016)

Explanatory Variables	Past rainfall		Past temperature		Future rainfall		Future Temperature	
	Coef.	P>z	Coef.	P>z	Coef.	P>z	Coef.	P>z
District	.645	0.033**	.510	0.096*	1.080	0.001***	.665	0.025***
Gender	.138	0.629	.404	0.163	-.572	0.038**	-.518	0.053*
Age								
Age (35-42)	.592	0.086*	-.032	0.918	-.112	0.712	-.285	0.332
Age (43-55)	-.068	0.835	.552	0.120	-.142	0.668	-.404	0.205
Age (>55)	.145	0.675	.718	0.049**	-.267	0.436	-.386	0.235
Education								
Education (primary)	-.034	0.892	.132	0.607	.611	0.016**	.435	0.072*
Education (secondary)	.287	0.511	1.48	0.012**	1.017	0.008***	.880	0.018**
Education (post-	0		0		0		0	
Agricultural sell	-.000	0.640	-.000	0.568	-.000	0.130	-.000	0.157
Farm size	-.039	0.753	-.190	0.119	.056	0.626	-.025	0.826
Soilstatus								
Soilstatus (very fertile)	-.281	0.740	-.808	0.357	0		0	
Soilstatus (fertile)	-.153	0.666	-.102	0.767	-.411	0.188	-.624	0.046**
Climate change	.170	0.521	.572	0.034**	.510	0.049**	.474	0.056*
Shock	.486	0.043**	.050	0.840	-.006	0.978	.216	0.313
Credit service	.145	0.579	-.117	0.652	.371	0.136	.426	0.080*
Constant	-.162	0.784	-.347	0.555	-1.011	0.088	-.107	0.845
Pseudo R^2	0.09		0.14		0.16		0.13	
N	180		180		177		177	

*** Significant at p< 0.01; ** Significant at p<0.05; * Significant at p<0.1 level

NB: The zero values are as a result of the small number observations in these categories that predicted outcome perfectly and the STATA software dropping these observations.

Table 3 Estimates of recursive bivariate probit models (adopted from Habtemariam et al., 2016)

Explanatory Variables	Past rainfall		Past temperature		Future rainfall		Future Temperature	
	Coef.	P>z	Coef.	P>z	Coef.	P>z	Coef.	P>z
District	.535	0.045**	.426	0.107	.986	0.007***	.658	0.019**
Gender	-.344	0.163	-.377	0.099*	-.886	0.013**	-.624	0.083*
Age								
Age (35-42)	.525	0.086*	.064	0.808	-.069	0.803	-.279	0.333
Age (43-55)	-.234	0.432	.089	0.770	-.251	0.442	-.443	0.182
Age (>55)	.190	0.554	.549	0.097*	-.168	0.616	-.366	0.286
Education								
Education (primary)	.050	0.828	.092	0.686	.601	0.017**	.440	0.070*
Education (secondary)	.336	0.365	.987	0.006***	1.10	0.001***	.922	0.009***
Education (post-	4.851	0.000***	7.935	0.000***	6.65	0.000***	6.52	0.000***
Agricultural sell	-.000	0.615	-0.00	0.824	-.000	0.147	-.000	0.154
Farm size	-.054	0.612	-.132	0.211	.042	0.690	-.023	0.831
Soilstatus								
Soilstatus (very fertile)	-.265	0.728	-.411	0.557	-5.70	0.002***	-5.85	0.000***
Soilstatus (fertile)	-.102	0.690	.183	0.327	-.390	0.143	-.623	0.046**
Climate change	1.493	0.000***	2.05	0.000***	1.39	0.056**	.764	0.281
Shock	.395	0.068*	.025	0.903	-.021	0.919	.211	0.327
Credit service	.137	0.521	-.099	0.525	.336	0.155	.422	0.073*
Intercept	-.693	0.111	-1.12	0.019**	-1.27	0.012**	-.217	0.728
Rho	-.838	0.001	-1	0.00	-.614	0.40	-.187	0.68
N	182		182		182		182	

*** Significant at p< 0.01; ** Significant at p<0.05; * Significant at p<0.1 level

One of the farm level characteristics that relates to climate change perception is, for example, gender. It is found that in most of the cases female farmers are more likely to perceive the change in climate than male farmers. How gender influences the perception of climate change is explained by the perspective that women to be more concerned about environmental issues that threaten their families and communities (Liu et al. 2014).

One important issue in the climate change topic is the natural day-to-day variability of weather, which make it difficult to recognize long-term shifts in climate (Akerlof et al. 2013). Thus, characteristics that increase the acquisition and retention of long term climate change information such as the level of education (Goebbert et al. 2012) can influence the climate change perception of farmers. Individuals that are more educated are better equipped to acquire, analyze, and retain information about the changing climate. The empirical findings of this study also supportes this hypothesis.

One would expect older farmers who have long-term farming experience or attachment to the local environment to be in a better position to notice climate change. The empirical findings support this age effect to be true in case of perception about past temperature change. However, the finding suggests that age has little relevance for anticipating a phenomenon, which has not yet been observed. The perception of climate change is also shaped by whether the farmer has previously received climate change related information. The mechanism by which previous information influences climate change perception can be explained by the phenomenon of motivated reasoning (Howe and Leiserowitz 2013). It is believed that individuals seek out for a reason to confirm what they already know, and this influences their attitude and decision-making. Entitlement of resource is related to perception by affecting sensitivity to climate change (Semenza et al. 2008). Farmers who are constrained by resource, for example, in terms of land fertility are likely to notice the local climatic changes. Literature also shows that the limiting factor in a location or agro-climatic zones is related to climate change perception (Hamilton and Keim 2009; Howe and Leiserowitz 2013).

The relationship between one of the explanatory variable (i.e., the variable agro-ecology) and perception was found to be in contrary to prior assumption. It was assumed farmers in tepid agro-ecology to be more likely to perceive the change in the climate than farmers in cool highland agroecology; however, the empirical data showed the reverse relationship. Though this finding was in contrary to prior assumption, it is in line with the findings of a study by Deressa et al. (2011). Comparing the findings of the study to existing empirical literature suggests that there are similarities and difference in terms of which factors influenced climate change perception, and in terms of the direction of the relationship. Similarities and differences also existed among the findings of previous studies. Some of the variables which showed inconsistent relationship in various empirical findings are age and income (Deressa et al. 2011; Roco et al. 2014; Silvestri et al. 2012). This indicates that the factors that influence farmers' perception are highly location and context specific. It is therefore relevant to take into consideration local socio-economic, agro-ecological and institutional contexts when assessing climate change perception, and interpreting research findings.

4.3 Climate change adaptation in smallholder agriculture

The study that review the climate change adaptation literature of developing countries agriculture aimed to show the key issues in adaptation studies and the specificity of smallholder agriculture adaptation research. The review provided an important insight to understand the growing adaptation literature and the diverse research topics being addressed by the literature. It was found that the literature is increasingly contributing in terms of providing evidence to understand current farm adaptations, the role of adaptation in agriculture, the costs of adaptation, and the scope to mainstream adaptation into existing policy and development strategies. It has been found that diverse conceptual and methodological approaches have been used in the literature to investigate farmers' adaptation decisions, to assess the potential of adaptation strategies in terms of increasing productivity and to assess the economic costs of adaptation. Some studies have used economic concepts and econometric models of household decision-making to investigate the determinants of climate change adaptation decision. In some studies theories in psychology and behavioral economics have been used to explain the decision to adapt or not to adapt. Cropping system studies that have assessed the potential of adaptation in terms of increasing productivity have provided evidence mainly from pure agronomic perspective. Sectoral and country level analysis that estimated the cost of adaptation provide an important information on the cost of adaptation useful for country-level adaptation strategy design, for climate change funding negotiations, and for international support of adaptation in developing countries.

However, it was found that there are still research gaps that need further investigation in terms of thematic, spatial and temporal coverage, and in terms of conceptual and methodological approach. There is also a need to cover diverse agro-climatic and socio-economic contexts, as adaptation is highly peculiar to local specificities. As it is now, focus has been given to adaptation in the near term with less emphasis on transformative adaptation, which are needed under strong climate change in the long term. The study has concluded that the conceptual approaches that have been applied to study farm level adaptation decisions needs to be expanded to include the role of risk perception and experience variables. From policy perspective, policies that seek to minimize the impacts of climate change on agriculture through adaptation need to consider the diverse adaptation alternatives, the capacity to be adopted by the wider farm population, and the costs of adaptation.

4.4 Risk experience and farmers climate change decision

When many of the current agricultural production practices and technologies become ineffective under the changing climate, farmers will need to change their methods and technologies to minimize the damage of impending climate change and to maintain productivity. However, there might be several reasons why farmers do not adapt to climate change. The empirical study on the adaptation decision of farmers aimed to address one of the research gaps identified in adaptation literature. The study assessed the role of risk experience and various socio-economic variables in influencing farmers' adaptation decisions.

The study on farmers' adaptation actions showed that many farmers plan to implement no or limited climate change adaptation action in the future. In addition, farmers' decision to adapt to future climate change seems to relate to various information and resource related variables and risk experience elements. The lack of resource and information can be among the main determinants of climate change adaptation decisions as the choice to adapt involves some financial cost and requires knowledge. It is expected that farmers with better resources, and access to climate change and adaptation information are more likely to decide to adapt to climate change. Nonetheless, socio-economic factors are not sufficient to explain farmers' adaptation decision-making. In many cases, risk perception mediated through risk experience can influence the decision to adapt to climate change.

The role of risk perception in motivating individuals for response action against risk is a well-explained concept in the literature of the protection motivation theory (Grothmann and Patt 2005; Rogers 1983). Similarly, the motivation to take action against climate change is believed to relate to the perceived risk of climate change. It is expected that individuals that perceive the occurrence and sever impacts of climate change would be more likely to decide to take action against it.

In the current study, it was sought to understand the role of risk experience in terms of agricultural production shocks and yield reduction in the decision to adapt to future climate change. The study used a model of farmers' adaptation decision and controlled for potential endogenous nature of the risk variable. Certain risk experiences for example experiencing production shock is found to influence the decision to adapt to climate change (Table 4). Experiencing yield reduction is not found to influence adaptation decision. It is assumed that not just experiencing a risk but the severity of the risk may play an important role in the decision to adapt. The finding on the role of risk experience in terms of production shock is similar to empirical findings of Spence et al. (2011) that found individuals who had direct flood experience to show higher mitigation behavior. But inconsistent with Tucker et al. (2010) that found farmers who perceived extreme weather and other risks to be slightly less likely to make adaptive changes. Other studies for instance that studied about agricultural advisors in the US show that experiencing extreme weather events such as drought did not significantly change attitudes towards adaptation (Carlton et al. 2016). In addition, the current study has found a range of socio economic variables that relate to adaptation decision. The decision to take adaptation action is found to be influenced by education, gender, household size, agro-ecology and participation in agricultural extension services.

Table 4 Estimates of the multivariate probit model of adaptation decision

Explanatory Variables	Adaptation decision (A)		Yield reduction experience (Y)		Production shock experience (P)	
	Coef.	P>z	Coef.	P>z	Coef.	P>z
Gender	.403	0.085*	0.126	0.604	0.093	0.682
Age	.005	0.392	-0.002	0.773	-0.013	0.044
Formal education						
Primary	.387	0.067*	-.035	0.856	-0.046	0.818
Secondary	.685	0.031*	.171	0.555	-0.142	0.626
Post-secondary	.126	0.864	-.384	0.613	0.217	0.763
Marital status	-.285	0.263	0.005	0.983	0.094	0.713
Household size	.104	0.010*	0.019	0.575	-0.033	0.331
Farm size	-.075	0.356	-0.179	0.020	0.004	0.955
Soil fertility status						
Fertile	-.491	0.355	-0.050	0.915	0.281	0.478
Infertile	-.417	0.480	-0.135	0.796	-0.19	0.673
Agroecology	-.368	0.077*	0.052	0.822	0.70	0.002
Non-agricultural income	.134	0.703	0.416	0.228	0.049	0.90
Credit service	.097	0.614	0.051	0.776	0.154	0.407
Agricultural extension	.787	0.001*	0.223	0.405	-0.503	0.048
Irrigation water access	-.013	0.947	-0.361	0.041	-0.175	0.344
Yield reduction	.008	0.980	-0.628	0.171		
Production shock	1.872	0.000*				
Constant	-.441	0.032*				
rho_{YA}	-.233	0.451				
rho_{PA}	-.932	0.000*				
rho_{PY}	.419	0.114				

Notes: N=263; log likelihood=-445.3; Wald chi^2=229.43; Prob>chi2=0.000; likelihood ratio test of rho chi2(3) =6.377; Prob>chi2=0.095; ***= significant at 1%; **= significant at 5%; *=significant at 10%

5. Conclusions and Policy Implications

The findings of the climate change impact study highlighted that the livelihoods of many farmers, particularly in warm regions, might be threatened by climate even in the near-term period. Production of crops such as *tef* and wheat in warm regions might be significantly constrained by climate change in the future. Moreover, the uneven implications of climate change on farms and the role agro-ecology and future socio-economic developments play in determining climate change impact are highlighted in the findings.

The climate change perception study has shown that gender, age, education, agro-ecology, farm soil fertility status, climate change information, recent experiences and access to credit services to be relevant factors to climate change perceptions. While some these factors influence both the perception of past climate and anticipation of future climate, others influence only one of these aspects.

The findings of the study on the adaptation literature highlighted the increasing contribution of the scientific research in terms of providing evidence to understand current farm adaptations, the role of adaptation in agriculture, the costs of adaptation, and the scope to mainstream adaptation into existing policy and development strategies. However, research gaps and limitations are identified in terms of thematic, spatial and temporal coverage, and in terms of conceptual and methodological approach.

In the study that assessed the adaptation decision of farmers, risk experiences as well as a number of other socio-economic and institutional variables are found to influence adaptation decisions. However, not all risk experiences led to adaptation decision in the study. While experience on production shock, which assumed to have bigger magnitude impact influenced farmers' adapation decision, experience on yield reduction has not showed such influence. Other variables that are found to be associated with adaptation decisions include gender, education, household size, and participation in agricultural services.

The findings of the studies have many important policy implications. Providing accurate information about climate change can minimize misperception about climate change and increase the propensity farmers to participate in climate change adaptation and mitigation response actions. Policy strategies need to target farmer groups with low climate change perception to effective increase the climate change perception of farmers. Information about climate change can be provided to farmers through rural extension services in face-to-face method. Farmers training centers, farmers associations and other social gatherings also provide a good opportunity to reach higher number of farmers. In addition, various media outlets such as local radio and television can be also used to disseminate climate change information.

In the absence of effective adaptation measure, the livelihood of many farmers will be threatened. Many potential adaptation strategies are suggested in the literature ranging from simple agricultural practice adjustments to the use of new agricultural technologies and to diversification of income sources. It is paramount to identify the most effective adaptation strategies that are feasible to local peculiarities and production requirements; and promote the most feasible strategies among farmers. While farmers can easily perform some of these adaptation strategies by their own; some strategies e.g., the development of new crop varieties, the creation of job in the non-agriculture sector require the involvement of policy interventions. Thus, the extent to which the potential adaptation strategies will be actually implemented will partly depend on appropriate policies that enhance the development and dissemination of adaptation technologies.

Behaviors such as decisions to take measure against climate change through adaptation can be effectively influenced by persuasive risk communication strategies that appeal fear. Such strategies (i.e., describing and communicating the negative impacts of climate change through various channels in understandable way to farmers) might be successful to persuade farmers to adapt to climate change. Nonetheless, risk communication alone will not bring the result. It would be equally important to build the adaptation capacity of farmers in terms of resource as well as knowledge to enable them to adapt to climate change. Because, adapting agriculture to climate change may require methods and technologies (e.g., development of new crop varieties that are adapted to climate change) which are outside of farmers' experiences and farmers' current capacities and knowledge may not be sufficient for that.

Decision makers need to consider mainstreaming climate change adaptation into development planning and policies. By addressing the underlying factors, that cause vulnerability to climate change it would be possible to build resilience to climate change. Economic growth, poverty alleviation, human development, and technological innovations are put forward as a way to strengthen resilience to climate change. In addition, as climate change is a global issue the international level efforts under way to combat climate change need to continue to avoid dangerous climate change.

Overall, policy strategies that aim to reduce the risk of climate change should comprise interventions to improve the climate change perception and understanding of farmers, and design strategies to develop and disseminate climate smart methods and technologies appropriate to the local agro-ecologies and production activities. Apart from this, improving the overall capacity of farmers through better and appropriate economic development would be essential.

6. Outlook for Future Research

Based on the work in this dissertation, I suggest future researches to address some relevant knowledge gap in the topic. With respect to understanding the impact of climate change on the livelihood of smallholder farmers, it is useful to include in future analysis the impact of climate change on minor crop production activities too. Despite the limited role that minor crops have in household income generation, they may have key role in determining household food and nutrition security. It is thus relevant to understand how the production of nutritionally important minor crops will be affected by climate change. In addition, future research could take into consideration different climate scenarios to address the uncertainty surrounding on projection of future climate.

With regrading to perception, researches that address other agro-climatic zones, production types and socio-economic settings of smallholder farmers would be useful to identify locally specific factors that influence climate change perception.

Also, until recently the implications of the choice of adaptation strategy is often assessed in terms of its productivity benefit. However, we need to understand the implication farm adaptation strategies for household nutrition. In a first stage, a well-developed conceptual framework, which identifies the pathways that adaptation links to household food and nutrition security would be useful to address this research gap. Secondly, empirical study, which assesses the link between farmers adaptation strategies and household nutrition would provide important evidence.

Overall, it would be useful to incorporate biophysical concepts of cropping systems, economic theories of production and decision-making as well as psychology theories of perception and behavioral change in addressing these knowledge gaps.

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Appendix: Publications and Manuscripts

Publication I

Habtemariam LT, Abate Kassa G. and Gandorfer M. 2017. Impact of climate change on farms in smallholder farming systems: yield impacts, economic implications and distributional effects. *Agricultural Systems*. 152 pp. 58-66, reprinted with permission from Elsevier Ltd

Agricultural Systems 152 (2017) 58–66

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Impact of climate change on farms in smallholder farming systems: Yield impacts, economic implications and distributional effects

Lemlem Teklegiorgis Habtemariam [a,*], Getachew Abate Kassa [a], Markus Gandorfer [b]

[a] Technische Universität München, Alte Akademie 16, 85350 Freising, Germany
[b] Technische Universität München, Alte Akademie 14, 85350 Freising, Germany

ARTICLE INFO

Article history:
Received 19 June 2016
Received in revised form 9 December 2016
Accepted 12 December 2016
Available online xxxx

Keywords:
Climate change
AquaCrop
MarkSimGCM
Ethiopia
TOA-MD model

ABSTRACT

The impact of climate change on farms can be determined by factors such as local climatic changes, farm physical environment, the type of crops grown, and household socio-economic characteristics that limit or increase adaptability to climate change. The current study assesses the impacts of climate and socio-economic changes on smallholder farms in two districts of Ethiopia representing different agro-ecology in a major agricultural region. For this purpose, observed farm production data, simulated yield under climate change and socio-economic scenarios were used. The aim was to produce information that facilitates an understanding of the unequal economic implications of climate change on farms. To this end, the study applied the Tradeoff Analysis for Multi-Dimensional impact assessment (TOA-MD) economic simulation model in combination with the AquaCrop yield simulation model. The findings on climate change impact towards 2030 highlight the uneven implications of climate change on farms and the role that agro-ecology and future socio-economic development scenarios play in determining climate change impact. It is found that, under the climate projections we considered crops such as *tef*, barley and wheat are found to benefit from the projected climate change in cool regions. In warm regions, *tef* and wheat are projected to be negatively affected whereas maize would benefit. The proportion of farms that are negatively affected by climate change ranged between 51% and 78% in warm regions under different scenarios; in cool regions, the proportion of negatively affected farms ranged between 10% and 22%. The implications of climate change are found to vary under various socio-economic scenarios, in which positive socio-economic scenarios considerably reduced the proportion of negatively affected farms. The economic implications of climate change also found to differ among farms within agro-ecology because of differences in land allocation to various crops that have different sensitivity to climate change, and due to other farm differences. Thus, the study shows the importance of using farm and site-specific production and climate data to reveal variabilities in climate change impact. It also provides evidence on the relevance of accounting for agro-ecology and crop differences as well as consideration of potential socio-economic changes. Overall, the results suggest that appropriate agricultural interventions that recognize location and crop differences are essential to minimize climate change impact.

1. Introduction

Climate change is one of the biggest challenges the world faces today posing a threat to many populations around the globe. Studies indicate that in many regions of the world agriculture will be affected by climate change, limiting food production and threatening food security (Tai et al., 2014; Wheeler and Braun, 2013). Sub-Saharan African countries are among the most vulnerable to climate change having warm climate and lower socio-economic status that limits their capacity to adapt to the rapidly growing climate change effects (Ringler et al., 2010). As smallholder farmers in these countries continue to face an increasing threat from climate change, a growing body of literature is investigating to understand the potential impacts of climate change on the agriculture of this region. Findings from previous impact studies have indicated that agriculture will by and large be negatively affected in this region due to climate change (Schlenker and Lobell, 2010; Knox et al., 2012); for example mean yield changes of up to −22% have been found in some crops (Schlenker and Lobell, 2010). However, most previous studies have either focused on assessing climate change impact on yield of individual crops (e.g., Abraha and Savage, 2006; Jones and Thornton, 2003) or used aggregate models to assess economic impact (Claessens et al., 2012).

Assessing climate change impact on individual crops alone does not provide enough information for an understanding of the overall

* Corresponding author at: Technische Universität München, Alte Akademie 14, Freising, Germany.
E-mail address: lemlem.teklegiorgis-habtemariam@tum.de (L.T. Habtemariam).

http://dx.doi.org/10.1016/j.agsy.2016.12.006
0308-521X/

economic implications in systems where farms often simultaneously produce crops with varying degrees of sensitivity to climate change. Furthermore, as individual crop yield assessments mainly focus on evaluating the yield performance of crops in relation to future climatic conditions, other relevant socio-economic conditions that may change in the future are little considered in such studies. On the other hand, aggregate economic models do not adequately represent the heterogeneity in farming systems and conceal variability, which is of paramount importance to effective policy intervention. In previous climate change (Rao et al., 2015; Zubair et al., 2015) and technology (Suri, 2011) impact assessment studies in smallholder farming systems, a considerable amount of heterogeneity in terms of impact has been observed across households, which can be attributed to the spatial variability of the farms' physical environment, production activity and other household characteristics (Antle, 2011). This essential heterogeneity in agricultural systems (Antle et al., 2014) is not adequately represented in earlier studies, though currently, studies that recognize the differential effects of climate change are emerging (e.g., Claessens et al., 2012; Rao et al., 2015). Overall, climate change impact studies that represent the direct yield response of the various crops grown by farms alongside future socio-economic changes and agro-ecological differences may provide useful information in understanding the overall implications of climate change.

In this study, we applied the Tradeoff Analysis for Multi-Dimensional impact assessment (TOA-MD) framework in combination with the AquaCrop yield simulation model to assess the economic impact of climate change in a typical smallholder farming population in Ethiopia using local and farm-specific data. To this end, the current study characterizes the economic returns of farms under baseline and future climatic conditions, and socio-economic settings using observed and simulated crop yield data in combination with socio-economic scenarios. We carry out the assessment for two study areas representing two different agro-ecologies in a major agricultural production region. This study contributes to an understanding of the distributional economic implications of climate change representative of mixed-crop farming systems characterized by heterogeneous farm and household characteristics.

In the remaining part of this paper, Section 2 discusses conceptual issues and approaches of climate change impact assessment. Section 3 explains the materials and methods used in the study followed by results and discussion in Section 4. Finally, the conclusion and policy implication is presented in Section 5.

2. Climate change impact: conceptual issues and approaches

Climate change affects crop productivity primarily due to the effects of temperature, rainfall and CO_2 on crop physiological activities and phenological development (Lobell and Gourdji, 2012). It can also impair crop production by altering pest incidence and plant-pest interaction (Juroszek and Tiedemann, 2013).

However, several factors can determine the direction and magnitude of climate change impact on farms. First, as climate change manifests itself in different ways across locations, the impact may likewise vary depending on the specific local climatic changes. Secondly, even when areas experience a similar degree of climatic changes, the consequences will be detrimental, for example, in regions where temperatures are already near to physiological maxima (Gornall et al., 2010). Another important aspect is that different crops do not respond to climate change in the same way owing to variation in their sensitivity to temperature, rainfall and CO_2 changes (Gornall et al., 2010). The impacts of climate change may also vary from place to place and farm to farm due to differences in the capacity of agricultural systems and farms to adapt to climate change (Smit and Wandel, 2006).

Farms in smallholder farming systems vary in terms of composition and intensity of production activity, household characteristics, use of agricultural technology and farm physical environment. This variation has an important implication for climate change impact. In environmental and other technological impact assessments, it is thus essential to recognize farm heterogeneity in such systems (Antle, 2011). Another important aspect in climate change impact assessment is the socio-economic condition within which future agriculture is expected to work (Antle et al., 2014). Potential changes, for example, in agricultural price and cost variables and changes in land holdings that may happen in the future due to changes in various sectors of the economy, or changes in demand and supply, need to be taken into consideration in climate change impact assessment studies.

Past studies have assessed the impact of climate change on agriculture mainly using process-based crop models (Thornton et al., 2009; Abraha and Savage, 2006), statistical models (Lobell and Burke, 2010) or the Ricardian approach (Mendelsohn et al., 1994). Process-based crop models assess the impact of climate change on yield based on the relationship governing productivity as a function of climate, soil and management. The statistical model approach is based on historical relationship between crop yield data and weather data (Lobell and Burke, 2010). The Ricardian approach measures economic impact by examining the relationship between land values or farm revenue, and a set of climatic and other variables from cross sectional data (Mendelsohn et al., 1994). Process-based crop-yield simulation has good potential to predict the direct impact of climate change on yield provided the minimum standards for data selection and quality are met. The statistical approach is deemed to provide an alternative when detailed field data is lacking to calibrate process-based crop models (Lobell and Burke, 2010). However, the problem of collinearity among predictor variables such as between rainfall and temperature variables is among the major concerns in the use of the statistical approach (Lobell and Burke, 2010). The Ricardian approach has been significant for its ability to implicitly control for actual farmers' adaptation (Mendelsohn et al., 1994). However, its failure to consider issues such as carbon fertilization effects and future changes in price has been a concern (Mendelsohn and Dinar, 2009; Cline, 1996).

A more recently introduced TOA-MD economic simulation model provides a useful framework; particularly for agricultural systems in which farms involve in multiple agricultural activities composed of various crops, livestock and off-farm activity (Claessens et al., 2012). The model also allows an easy incorporation and simulation of the impact of future socio-economic changes in the analysis. Combined with crop yield simulation models and socio-economic scenarios, the approach provides a relevant framework by which climate change impact can be assessed accounting for crop and farm differences and future socio-economic settings. The TOA-MD model approach and how it is applied in the current study is discussed in detail in Section 3.3.1.

3. Materials and methods

3.1. Study area

The study is conducted on smallholder farmers in the Welmera and Dugda districts of Ethiopia. In Ethiopia, agriculture is the main livelihood for more than 80% of the population contributing over 40% of the gross domestic product (GDP). The GDP growth has shown a close link with rainfall variation in the past indicating the ties between climate conditions and the agriculture based economy (World Bank, 2006). Long term meteorological records show that the country has experienced climatic changes in the past decades (Tadege, 2007). The country features diverse agro-ecology and topography and this study assesses climate change impact in two study areas representing two agro-ecologies as described below.

The Welmera district is located in central Ethiopia, covering an area of 809 km^2 at a mean altitude of about 2527 m above sea level, and had a total population of 83,823 in 2007 (CSA, 2010). The annual rainfall for the area varied between 729 mm and 1301 mm with a mean of 1038 mm during the past four decades. The average maximum and minimum temperatures during this period were about 22 °C and 6 °C, respectively. Small-scale subsistence crop-livestock mixed farming system is the common agricultural practice. Farmers grow a mix of crops such as wheat, *tef* and barley in the area. Crop production is mainly rain-fed, low-input and the use of mechanized agriculture is rare. In addition to farming, some farmers participate in non-agricultural income activities.

The Dugda district is located in the central rift valley area of Ethiopia, covering an area of 959.5 km^2 at a mean altitude of about 1700 m above sea level, and had a total population of 144,910 in 2007 (CSA, 2010). The annual rainfall of the area varies between 511 mm and 1130 mm with a mean of 771 mm over the past four decades. The mean maximum and minimum temperatures are 27 °C and 14 °C, respectively. The dominant farming system in the area is small scale mixed crop-livestock. Food crops such as maize, wheat, and *tef* are commonly grown as rain-fed systems. Some households earn additional income from non-agricultural activities.

3.2. Farm survey data

The farm data used in this study is from a household-level interview conducted during November 2012 to February 2013 in the two districts. Farm-level production data on the various agricultural activities and household socio-economic information are collected including (i) information on land allocation for each major crop grown, and (ii) input-output information for each crop activity i.e., information on input use and yield. Respondents were randomly selected households from six peasant associations (the lowest administrative unit) located in the two districts. In total, 200 households in Welmera and 100 households in Dugda were interviewed. The analysis in this paper included 179 households from the Welmera district and 90 households from the Dugda district that provided information relevant for this analysis. Additional relevant production data required for the analysis were obtained from the central statistical agency archives and district agricultural offices. These data include average unit price of crop products and inputs representative of the study period and districts (CSA, 2013).

3.3. Methods

The current study assesses the economic implications of climate change in association to agricultural activities on major crops in the study districts. The major crop activities considered in the Welmera district are *tef*, wheat, and barley; in Dugda the major crops are *tef*, wheat and maize. We analyze the economic impact of climate change on farms in the study area by comparing the returns of production systems under different climate and socio-economic scenarios. To represent production systems in future periods more realistically, the current study focuses on the near-term effects of climate change centered at 2030. The TOA-MD model (Antle and Valdivia, 2011) in combination with the AquaCrop yield simulation model is used for the analysis. In the next section, we provide a detailed explanation of the TOA-MD model. The AquaCrop modeling is explained under Section 3.3.3.

3.3.1. The TOA-MD model

In the TOA-MD simulation model approach, "*a farmer at site s using a production system h (defined as a combination of technology, climate and socio-economic setting) earns per-hectare returns each period equal to $V_t = V_t(s, h)$. Over T time periods, production system h provides a discounted net return of:*

$V(s, h) = \sum_{t=1}^{T} \delta_t v_t(s, h)$ *where δ_t is the relevant discount factor*" (Claessens et al., 2012 p. 89)

When one or more of the components (for example climate) of the production system within which the farm operates changes, the associated expected net return may change. Defining $\omega = V(s, h_1) - V(s, h_2)$, where h_2 and h_1 respectively, represent a production system with and without the change at site *s*, a negative ω indicates a gain from h_2 whereas a positive ω represents a loss. Because of variation in physical and socio-economic conditions such as farm size, land quality, and household characteristics e.g., farming experiences and household size, the expected net returns of a system associated with each site are spatially distributed (Antle, 2011). Accordingly, ω is also spatially distributed with density function $\varphi(\omega)$ and the proportion of farms that lose returns less than or equal to *a* can be estimated as (Antle, 2011):

$$r(a, h_1, h_2) = 100\int_{-\infty}^{a} \varphi(\omega, h_1, h_2) d\omega$$

In the current study, we use the TOA-MD model to assess the impact of climate change and socio-economic scenarios on farm returns by comparing farm returns of baseline production system (h_1) against production system with climate and socio-economic change (h_2). For this, the returns of the crop production activities under the baseline production system are estimated from the production input-output and socio-economic data collected from household surveys in the study area and other relevant secondary sources. The expected returns of crop production under climate and socio-economic change are estimated by using outputs from crop yield simulations and using socio-economic scenarios. Detailed descriptions of the TOA-MD model parametrization process for both production systems are provided in the following section.

3.3.2. Characterization of the baseline production system

We first stratified the farm population in each study area into two farm groups based on whether farms are located in villages officially recognized to have irrigation access. We assumed that, due to differences in irrigation access, land holdings and land allocations for major crop activities may vary between the two groups; potentially leading to differences in climate change impact. Thus, stratification can enable us to understand potential climate change impact differences on the two groups. In addition, stratification into sub-populations based on the appropriate factor improves the normality assumption made about the distribution of net returns and outcome variables in the TOA-MD model (Antle, 2011). Stratification is only for the purpose of unravelling potential differences in landholding and crop allocations, otherwise all the major crops under consideration are produced under rain-fed system in the main cropping season. Farms use irrigation to produce vegetables in small areas during the dry season.

After stratification, the relevant model parameters for each group are then estimated. The summary is presented in Table 1. Values for farm size, off-farm income, allocated area, and yield for each crop are all estimated from the household-level survey data. Input costs are estimated based on farm data on the amount of input applied by farmers and the district-level average unit input price information from agricultural offices reported for the year under consideration. The net returns are calculated as total return minus variable costs of seed, fertilizers, and chemicals. The average prices representative of each study area and study period as reported by the central statistical agency were used to value total return. Farmers in the area depend almost entirely on family labor, and because farmers are not in the habit of recording time spent on farming activities it is often challenging to obtain a reliable estimation of labor costs. As a result, labor cost is excluded in the net return calculation. The problem of inclusion of labor costs has been reported in other studies too (Kurukulasuriya and Mendelsohn, 2008). Fixed costs in smallholder production systems are a small portion of the total cost and as it is not expected to change significantly between systems in the near future, excluding this from net return estimation will not bias the final output.

3.3.3. Characterization of the production system under climate and socio-economic changes

The expected net returns of the production systems under climate and socio-economic changes are estimated by integrating the outputs of yield simulation and socio-economic scenarios. In this, farm net returns for each crop activity are calculated based on expected yields

Table 1
Data used in the TOA-MD model to characterize baseline production systems.

District	Farm groups	Farm size (ha)	Off-farm income (birr)	Crop activity	Area (ha)	Yield (kg ha^{-1})	Net return (birr ha^{-1})
Welmera ($N = 179$)	In villages with irrigation access	1.45 (1.1)	383 (1418)	*Tef*	0.41 (0.31)	1151 (714)	8532 (6612)
				Wheat	0.44 (0.30)	1532 (1086)	5395 (6173)
				Barley	0.07 (0.14)	1199 (737)	2246 (3514)
	In villages with no irrigation access	1.46 (1.2)	1518 (3687)	*Tef*	0.47 (0.56)	1400 (1063)	10,188 (10203)
				Wheat	0.50 (0.50)	1963 (1578)	6615 (9785)
				Barley	0.25 (0.36)	1820 (1381)	4432 (7561)
Dugda ($N = 90$)	In villages with irrigation access	1.34 (1.3)	846 (2524)	*Tef*	0.26 (0.29)	1229 (510)	15,343 (6979)
				Wheat	0.31 (0.30)	2004 (857)	10,865 (5432)
				Maize	0.79 (0.70)	3866 (2061)	17,134 (9250)
	In villages with no irrigation access	2.23 (0.9)	896 (2689)	*Tef*	1.32 (0.57)	875 (256)	9873 (3501)
				Wheat	0.47 (0.44)	1655 (543)	8862 (4007)
				Maize	0.49 (0.40)	1791 (962)	7750 (4632)

Birr is the unit of currency in Ethiopia
The values in parenthesis are standard deviations
All crops under consideration are produced under rain-fed system. The grouping of farms under villages with and without irrigation access is for the purpose of identifying potential differences in landholdings and crop allocations.

of each crop under climate change and expected changes on socio-economic settings such as prices and input costs. In the next two sub-sections we explain how we estimated yield and socio-economic changes.

3.3.3.1. Yield under climate change. The AquaCrop model is applied to simulate yield under climate change. The AquaCrop model simulates daily biomass production and final yield of crops in relation to water use and agronomic management (Vanuytrecht et al., 2014a). The model has been validated and applied including in studies that have assessed the impact of climate change on different crops (Muluneh et al., 2014); the impact of adaptation strategies under climate change (Bird et al., 2016) and to investigate the uncertainty associated with using different climate models (Vanuytrecht et al., 2014b). The studies show that the model is a valuable tool in predicting yield, particularly in areas under limited water environments such as most parts of Ethiopia. To simulate yield, AquaCrop requires input data on rainfall, temperature, reference evapotranspiration (ET_0), CO_2 concentration, soil data, crop parameters and management data. Details of the concepts of the model and the simulation process can be found in Steduto et al. (2009) and Raes et al. (2009).

The model has been calibrated and validated for crops such as wheat, maize, barley, *tef* and others under various environmental conditions, and the model provides starting values and recommendations of crop parameters obtained from calibration/validation exercises (Raes et al., 2012). The crop parameters used in this study are adopted from previous calibration and validation exercises of the AquaCrop model conducted under Ethiopian conditions and elsewhere (Abreha et al., 2012; Tsegay et al., 2012; Biazin and Stroosnijder, 2012). We used the AquaCrop default crop parameters provided by the model for *tef*, barley and wheat crops; the default crop parameters of AquaCrop for *tef* and barley are from calibrations under Ethiopian conditions. For maize, we modified the default crop parameters following the crop parameters recommended by the study of Biazin and Stroosnijder (2012) conducted in Ethiopia.

Daily data on rainfall, maximum- and minimum temperature, and solar radiation required in the yield simulation process were obtained from the web version of the stochastic weather-generating tool MarkSimGCM (http://gisweb.ciat.cgiar.org/MarkSimGCM/). The comparison of MarkSimGCM simulations with historical data from various climatic locations (Jones and Thornton, 2013) including for sites in Ethiopia (Muluneh et al., 2014) has shown reasonably accurate simulation potential of MarkSimGCM. Two sets of climate data i.e., one for a baseline period and one for a future period were generated for a representative site in each district. For the baseline period, daily weather data in each site was generated for 30 replicates (different weather years) (Jones and Thornton, 2003). For the future period, daily weather data is generated for the period 2020–2049 for two representative concentration pathways (RCPs[1]); the very low forcing level concentration pathway RCP 2.6, and the very high forcing level concentration pathway RCP 8.5 (van Vuuren et al., 2011) from an ensemble of 17 global circulation models. The period 2020–2049 is used to represent the climate and yield of 2030. The outputs of the weather generation process are presented in Appendix 1.

Reference evapotranspiration (ET_0) is computed by the Penman-Moneith method using an ET_0 calculator incorporated in the AquaCrop model using minimum- and maximum temperature and solar radiation data. The CO_2 concentration value used for the baseline period is the mean annual measured at Mauna Loa observatory station and for the future period, the RCP2.6 and RCP8.5 concentration values are used as provided by the AquaCrop model. The dominant soil texture conditions in the study areas, i.e., clay loam in Welmera and sandy loam in Dugda are used as input for the simulation (Hengsdijk and Jans, 2006; Tangka et al., 2002). The common rain-fed cropping system and the model default management condition (i.e., optimum soil fertility) is considered.

Simulation is carried out for the baseline and future periods using the local crop calendar obtained from the FAO crop calendar global dataset and available at http://www.fao.org/agriculture/seed/cropcalendar/welcome.do. The simulated yield for 2030 is represented by calculating the average yield of the 2020–2049 time period. The simulated yield for the baseline period is represented by calculating the average yield of the 30 baseline weather years. Finally, the yield under climate change at each farm is calculated as follows:

Yield under climate change at each farm = [((mean simulated yield under baseline climate) − (mean simulated under climate change)) / (mean simulated yield under baseline climate)] ∗ farm observed yield

By using the farm observed yield instead of direct AquaCrop simulation output to approximate future yield, we assume to implicitly introduce possible spatial variation in yield that arises from site-specific and household-specific differences into the TOA-MD model.

On a separate analysis, this study has made validation of the AquaCrop model for the study area based on correlation analysis for AquaCrop simulated yield, and available local yield statistics (available at the next higher administrative unit to the district i.e., zone level) for each crop. Yield simulation for the validation process is carried out using historical climate data in the period 1995–2009 observed at meteorological stations in or nearby the study districts. The climate data is obtained from meteorological agency of Ethiopia and an agricultural research institute. The outputs are presented on Appendix 2. The correlations were positive and statistically significant at the 5% significance

[1] The RCPs are a set of four future greenhouse gas concentration pathways used by general circulation models and are identified by how much radiative forcing level they lead to by the end of the century (van Vuuren et al., 2011).

level for all the cases except *tef* and wheat in Dugda that showed non-significant positive correlation. Overall, the correlations suggest the potential of the AquaCrop model to represent yield trends in the areas as a function of the local climate in most cases.

3.3.3.2. Socio-economic changes. The impact of climate change is sensitive to the interaction of many biophysical and socio-economic factors (Wiebe et al., 2015). It is thus relevant to include this dimension in climate change impact assessment studies. The future socio-economic scenarios assumed in our study are estimated from scenarios developed based on the concepts of representative agricultural pathways (RAPs)[2] for a country with comparable socio-economic conditions. We benefit from the work of Claessens et al. (2012) that provides two alternative parametric socio-economic scenarios for Kenya. There are similarities in the development of the smallholder sector as well as in the macro-economic policies and structural changes of Kenya and Ethiopia. For example, with regard to market development for agricultural products, the market liberalization for maize in both countries shows more or less similar trends (Aylward et al., 2015; Wangia et al., 2002). Also, the economic contribution of the agriculture sector in the two countries shows similar trend in recent years. Cereal yield, for example, show similar level and trend in both countries. Agriculture in the two countries faces many similar constraints; for example, access to credit and access to input and output markets are big issues for the farms. Considering these similarities and the recent efforts made by the two governments to pursue regional integration to promote economic development (proclamation no 836/2014, Ethiopia), and the Ethiopian government's effort to join the World Trade organization (WTO), it can be expected that the socio-economic conditions and institutional settings of the agricultural sector in both countries will be comparable in the future. Therefore, the RAPs developed for Kenya are considered to be applicable for our study region that is more or less affected by similar socio-economic conditions and market infrastructure.

One of the RAPs refers to a future with positive economic growth characterized by infrastructure development, policy changes and non-agricultural sector developments, whereas the second refers to a future with low economic growth characterized by higher population growth, poor agricultural policies and low infrastructure development (Claessens et al., 2012). Table 2 shows the parametric socio-economic scenarios developed for 2030 consistent with the two RAPs. Claessens et al. (2012) provides price and cost scenarios for maize; in the current study we extrapolate the scenarios to the other cereals considered in our analysis. The parametric socio-economic scenarios are based on RAPs that made assumptions on, among other factors, non-agricultural sector developments, associated off-farm income and farm size changes. Therefore, to be consistent with these assumptions we added off-farm incomes into our farm income analysis in the TOA-MD model.

4. Results and discussion

4.1. Yield response to climate change

The simulated changes in mean yield relative to the baseline period are presented in Fig. 1. Detailed output of the yield simulation process is presented in Appendix 3. The simulated changes in yield vary between locations, among crops and representative concentration pathways. The variation in simulated yield change between locations is considerable.

[2] "Representative agricultural pathways (RAPs) are plausible qualitative story-lines for future socio-economic settings that can be translated into model parameters such as farm and household size, prices and cost of production and policy" (Claessens et al., 2012 p. 88). The RAPs are being developed by the Agricultural Model Intercomparison and Improvement Project (AgMIP) to facilitate climate change impact assessment studies that are in joint context with the emission and socio-economic scenario assumptions in climate models (Rosenzweig et al., 2013). RAPs are based on assumptions made in "population growth, income growth and technology changes as well as trade, investment, energy and agricultural policy" (Rosenzweig et al., 2013 p. 174).

Table 2
Socio-economic changes (expressed as percent of the baseline period (100%)) assumed in the TOA-MD model.
Source: Adapted from Claessens et al. (2012).

	RAP1 (positive economic development)	RAP2 (low economic development)
Cereals price	130	100
Cereals cost	90	110
Farm size	120	80
Off-farm income	150	100

RAP = Representative Agricultural Pathway

In Welmera, the yield of all crops increased in both representative concentration pathways at varying magnitudes. In highland Welmera, it is likely that the projected increase in rainfall in the month of July coupled with an increase in temperature (Appendix 1) during the growing period, have resulted in overall positive yield impact. Increasing temperature in highland areas is generally believed to potentially enhance crop productivity where cooler temperatures currently constrain plant productivity (Thornton et al., 2015).

In Dugda, *tef* and wheat yield declined while maize yield increased in both concentration pathways. Yield decline in *tef* and wheat is mainly induced by water stress as a result of an extended dry period during the growing period of future climate. As Dugda is already located in a warmer zone that receives less rainfall, an increase in temperature coupled with decreased rainfall, particularly in the month of August, has most likely contributed to major yield losses in *tef* and wheat. Studies have found that successive dry spells during critical growing stage of *tef* such as flowering can lead to sever yield reduction (Araya et al., 2011). The dry spells have not coincided with maize critical growing stages as maize is planted earlier. On the other hand, the rainfall increase in May coupled with temperature increases may have created conducive environment for maize performance.

In addition to rainfall and temperature effects, the AquaCrop model also represents the effects of rising CO_2 concentrations. Therefore, the simulated changes in yield are attributed to the combined effects of change in climate variables as well as CO_2 effects. In general, C_3 plants are believed to respond positively to the direct CO_2 fertilization effects (Boote et al., 2011). However, C4 plants have also been found to improve their water use efficiency particularly in areas with limited water availability in response to elevated CO_2 level (Leakey, 2009). The AquaCrop model also makes adjustments to elevated CO_2 accordingly (Raes et al., 2012).

Overall yield simulation results from the two agro-ecologies suggest that the combined effect of a slight increase in rainfall, an increase in temperature and CO_2 fertilization effect will result in yield increase in areas characterized by relatively less limiting current rainfall and lower temperatures. However, the impact of a likely further increase in temperature or a change in rainfall pattern and distribution in mid-term period or the end of century will have to be determined in future studies. On the other hand, the combined effect of a rainfall decrease and an increase in temperature in the middle of the growing season can be detrimental for some crops in areas characterized by limited current rainfall and warmer temperatures.

Considering previous studies, Jones and Thornton (2003) have predicted localized substantial yield increases in maize particularly in highland areas (up to 100%), and in some areas dramatic decreases in 2055 in Ethiopia. A study by Muluneh et al. (2014) that considered impact for mid-term and end of century periods also indicated agro-climate-specific yield changes for maize that ranged from plus 59% to minus 46%; the same study predicted an increase in yield of up to 40% for wheat crops in the humid zone of the central rift valley of Ethiopia. The findings of Kassie et al. (2015) study conducted in Ethiopia shows that maize yield will decrease in 2050s under the climate projection they

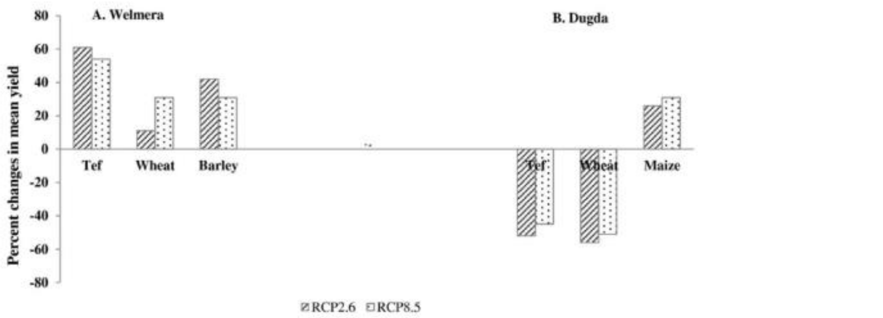

Fig. 1. Simulated percent changes in mean yield in 2030 relative to the baseline period in (A) Welmera and (B) Dugda districts under the two climate emission pathways.

considered. A further study that has assessed the manner in which climate change spatially affects crop production in Ethiopia has shown shifts in land suitability with net losses in land area suitable for cereal production (Evangelista et al., 2013). The study by Abreha et al. (2012) that has investigated the impact of hypothetical climate and CO_2 scenarios on maize in South-Africa finds doubling of CO_2 concentration alone, and the combined effect of doubling of CO_2, and temperature and rainfall increases of 2 °C and 10% respectively, all increase maize yield. Other studies from Sub-Saharan Africa also show substantial spatial variability and crop-specific yield responses to climate change (Thornton et al., 2009). A study by Ringler et al. (2010) also indicates how heterogeneous the impact of climate change is across crops and agro-ecological zones.

4.2. Economic implications of climate and socio-economic changes

The results of the TOA-MD model analysis are presented in Fig. 2 and Table 3. Fig. 2 illustrates the distributional impacts of climate change on farm populations in the two districts representing two different agro-ecologies. The point at which the curve crosses the x-axis shows the proportion of farms that are positively impacted with zero or negative loss (i.e., benefit). The results are presented for the analysis of the sensitivity of the baseline production system to climate change (i.e., the performance of the baseline production system under the two RCPs retaining current socio-economic conditions) and for a combination of the two RCPs and the two RAPs scenarios.

The graph in Fig. 2 reveals that in all the scenarios, the impact of climate change on farms is found to be non-uniform; a distribution of impact is observed in the population of both districts. The differential impacts of climate change among farms may have arisen because of differences in the crop allocation, physical environment, or household characteristics. These differences are represented in the model in terms of variation in farm crop yield (which is the result of physical environment and household characteristics among other things) as well as land allocation for the different crop activity among farms. The proportion of farms that are negatively impacted by climate change varied considerably between the socio-economic scenarios. The proportion of farms that are negatively impacted is higher for low economic development scenarios, followed by scenarios without socio-economic changes and with positive economic development, respectively.

Comparison of the proportion of negatively affected farms between the positive and low economic growth scenarios suggests the extent to which climate change results in negative impacts on the wider population when coupled with low economic development. Additionally, the findings indicate that the proportion of farms that are negatively affected by climate and socio-economic changes is much higher in the warmer Dugda than in Welmera in all the scenarios considered. This proportion ranges from about 10% to 22% in the Welmera district. The proportion of negatively affected farms in Dugda ranges from 51% to 78%.

Table 3 summarizes the results on the percent of negatively affected farms and associated net losses per farm separately for each farm group. Additionally, net losses per farm and net losses as a percent of mean net farm returns in the baseline system (from the major crops and off-farm income) are presented in the table. As can be seen from the table, for the Welmera district, the net loss per farm associated with the different scenarios is negative in all the cases in both farm groups suggesting a net positive impact. The difference in impact between farm groups is low in Welmera. Given the similarities in land allocations between the two

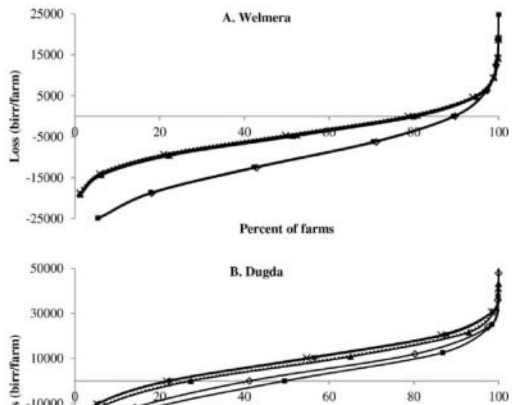

Fig. 2. The expected impact of climate and socio-economic changes on (A) Welmera & (B) Dugda farm populations by 2030. RCP2.6 = the impact of RCP2.6 climate change projection alone without consideration of socio-economic changes. RCP8.5 = the impact of RCP8.5 climate change projection alone without consideration of socio-economic changes. RCP2.6 (RAP1) = the combined effects of RCP2.6 climate change projection and RAP1 socio-economic scenario. RCP8.5 (RAP1) = the combined effects of RCP8.5 climate change projection and RAP1 socio-economic scenario. RCP2.6 (RAP2) = the combined effects of RCP2.6 climate change projection and RAP2 socio-economic scenario. RCP8.5 (RAP2) = the combined effects of RCP2.6 climate change projection and RAP2 socio-economic scenario.

Table 3
Impact of climate and socio-economic changes on farms.

Scenario	Welmera			Dugda		
	In villages with irrigation access	In villages with no irrigation access	Total	In villages with irrigation access	In villages with no irrigation access	Total
Percent of negatively affected farms						
RCP2.6	14	24	19	63	92	78
RCP2.6(RAP1)	6	14	10	42	76	59
RCP2.6(RAP2)	17	26	21	64	93	78
RCP8.5	16	24	20	58	88	73
RCP8.5(RAP1)	7	15	11	37	64	51
RCP8.5(RAP2)	19	26	12	58	89	74
Net loss per farm in birr						
RCP2.6	−4193	−5455	−4822	4140	10,978	6707
RCP2.6(RAP1)	−8358	−9995	−9174	−3196	5278	−15
RCP2.6(RAP2)	−3748	−4900	−4319	4418	11,439	7053
RCP8.5	−3970	−5342	−4653	2384	9034	4880
RCP8.5(RAP1)	−8111	−9814	−8960	−5433	2721	−2376
RCP8.5(RAP2)	−3484	−4622	−4051	2662	9507	5231
Net loss as a percent of mean net farm returns in baseline system						
RCP2.6	−74	−60	−66	16	46	27
RCP2.6(RAP1)	−133	−88	−104	−12	22	−0.06
RCP2.6(RAP2)	−66	−55	−60	17	48	28
RCP8.5	−70	−59	−63	10	38	19
RCP8.5(RAP1)	−130	−87	−102	−21	11	−9
RCP8.5(RAP2)	−67	−54	−59	10	40	21

RCP = representative concentration pathway
RAP1 = representative agricultural pathway with positive economic development
RAP2 = representative agricultural pathway with low economic development
NB: negative net loss indicates benefit

farming groups in the district, the results are as expected. The impact variation between the two groups in Welmera is assumed to be mainly due to differences in off-farm income levels. Therefore, we assume the stratification has helped to show this difference. In Dugda, the majority of the farm population in both farm groups would be negatively impacted in most of the scenarios. The net impact is mixed, revealing negative net losses linked to the positive economic scenarios in the farm groups with irrigation access. In most cases, impact is found to vary substantially between the two farm groups. This variation may have arisen mainly due to differences in farm size and land allocations in the two farm groups. The farms which are found in villages with no irrigation access allocate more of their land to *tef* and wheat production, which has resulted in higher negative impacts.

It follows that, in general the results suggest that, even in the near-term period in which climatic changes are expected to be relatively small, there are many farmers that would be negatively affected. The results also suggest that climate change may have more negative effects in warmer regions. As could be expected, the impact of climate change was minimized in positive economic development scenarios showing the role that socio-economic improvement can play in reducing vulnerability of farms in developing countries. At least for the period 2030, the positive economic growth scenario that projects increase in farm size and price coupled with a decrease in input costs, can partly offset the negative impact of climate change for some farms.

Other studies from the region report similar substantial negative impacts of climate change on smallholder farmers (Deressa and Hassan, 2009; Kabubo-Mariara and Karanja, 2007). The uneven distribution of impact observed between study districts representing different agro-ecology is in line with Deressa and Hassan's (2009) findings. Kurukulasuriya (2006) also shows warmer areas to be affected more seriously. This is consistent with our findings.

For a better understanding of the findings in this paper, it is important to discuss the main assumption made both in the crop and economic models. As indicated in the yield simulation section, the crop yield simulation has taken into consideration the fertilization effects of CO_2 that may have compensated some of the yield losses from climate change. However, potential yield loss due to increasing biotic stresses such as pest and disease in a changing climate (Boote et al., 2011) are not represented in the yield simulation model. In our representation of yield in the future in the economic model, we have not included the potential yield growth that can be associated with technological development. Given the near-term time period we analyzed, and the observed low rate of technological access and adoption in the study region, we do not expect the growth factor of technological development to be significant. Another issue is that temporal variation in management, and potential changes in farmland allocation for the various crops as a result of climate change was not considered in our study.

As is often the case in future climate change impact studies, potential uncertainties associated with climate models, crop models, CO_2 fertilization effects and future socio-economic scenarios also apply in this study. In the current study, climate data from the ensemble of multi-models, two emission scenarios, and two representative agricultural pathways were used to assess impact and show a range of probable future changes in yield and socio-economic conditions under the different assumptions made. Another important aspect is that, it is often the case that most studies, including the current one, do not include the effects of extreme climatic events that are believed to have far more detrimental impacts than gradual climate change. This is because climate models have limited potential in terms of predicting the future occurrence of these events. Therefore, it is relevant to consider potential damages from extreme events when evaluating the overall impact of climate change for mitigation and adaptation policy interventions.

5. Conclusion and policy implications

The study assessed the expected impacts of climate and socio-economic changes on farm populations in two districts of Ethiopia representing different agro-ecology. The approach combined assessing the direct impacts of climate change on crop yields and the associated economic implications. The findings on climate change impact towards 2030 highlighted the uneven implications of climate change on farms and the role agro-ecology and future socio-economic developments play in determining climate change impact. The study also shows that the use of farm and site-specific production and climate data is relevant to revealing variabilities in climate change impact. The findings provide useful information to policy-makers in reaching informed decisions on adaptive and preventive actions both on the local and global scale.

For policy makers, the findings suggested that unless appropriate measures are taken the livelihoods of many farmers, particularly in warm regions, might be threatened even in the near-term. The results also suggest that the realization of a positive economic development in a national development plan has the potential to reduce the negative impact. Climate-sensitive agricultural technology development particularly related to crops sensitive to the projected climate change can reduce impact. From the crop simulation output, one may suggest switching crops as one climate change adaptation option. However, nutritional aspects must be taken into consideration in policy interventions. As these are smallholder farmers who often produce for their own consumption, growing only a few types of crops that are less affected by climate change could have negative nutritional impacts. Therefore, climate related interventions should place emphasis on increasing productivity as well as be nutrition sensitive. If farmers opt to switch to crops less sensitive to local climatic changes and become less diversified due to absence of other adaptation options, policy-makers need to consider improving market integration. Another important aspect is, in smallholder farming systems it is the local production, which is more relevant for food security than national or regional level productivity. Thus, policies which aim to address food security concerns should be informed by locally specific climate change impact assessments instead of merely depending on aggregate level information that hide local variability. Finally, we suggest that future studies that evaluate plausible adaptation methods could increase insight in understanding the scope of potentially reducing impact through adaptation.

Acknowledgments

The first author has received a scholarship from Katholischer Akademischer Ausländer-Dienst (KAAD) and the Laura Bassi award from Technische Universität München for PhD study. This study is part of the PhD work.

The authors would like to thank the TOA-MD model developers for providing the model and supporting documents. We have benefited from the accompanying published and unpublished materials. We also would like to acknowledge the two anonymous reviewers for their constructive comments that helped us to improve the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.agsy.2016.12.006.

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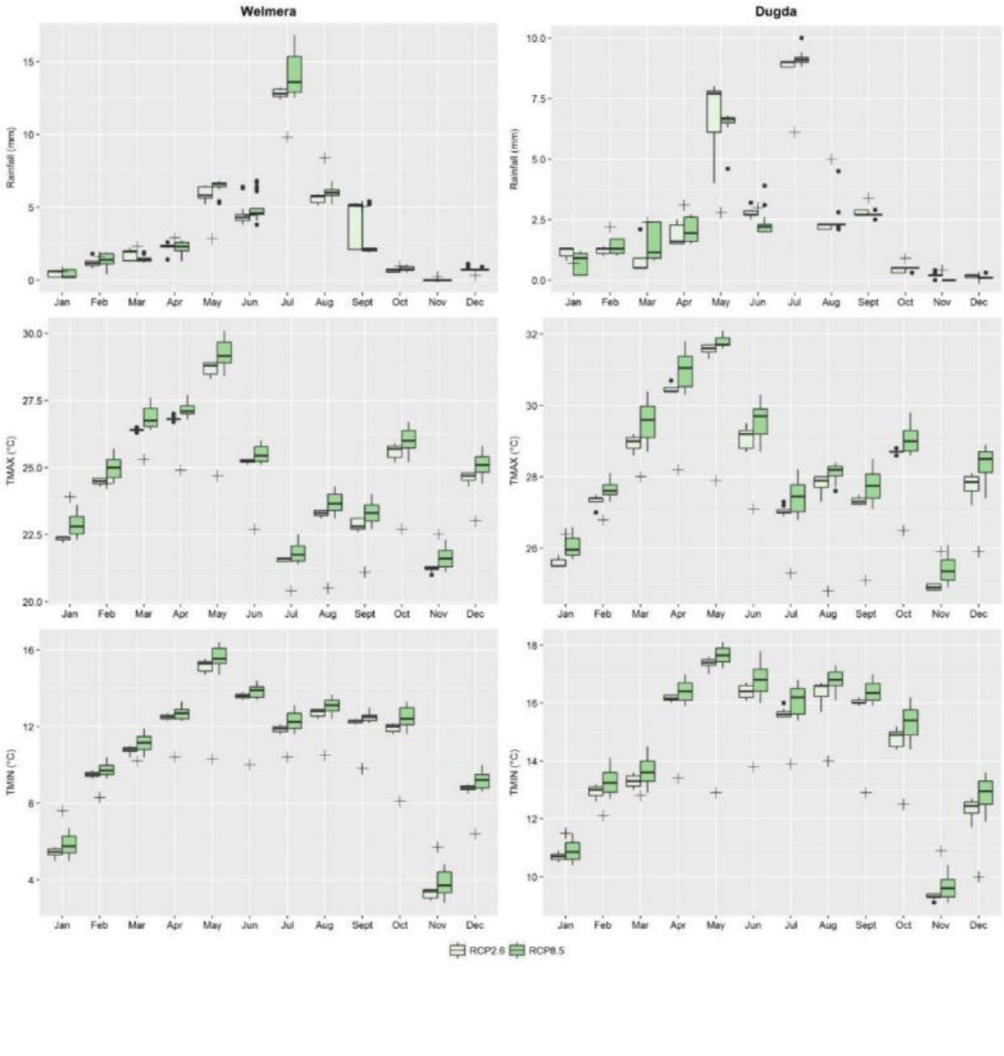
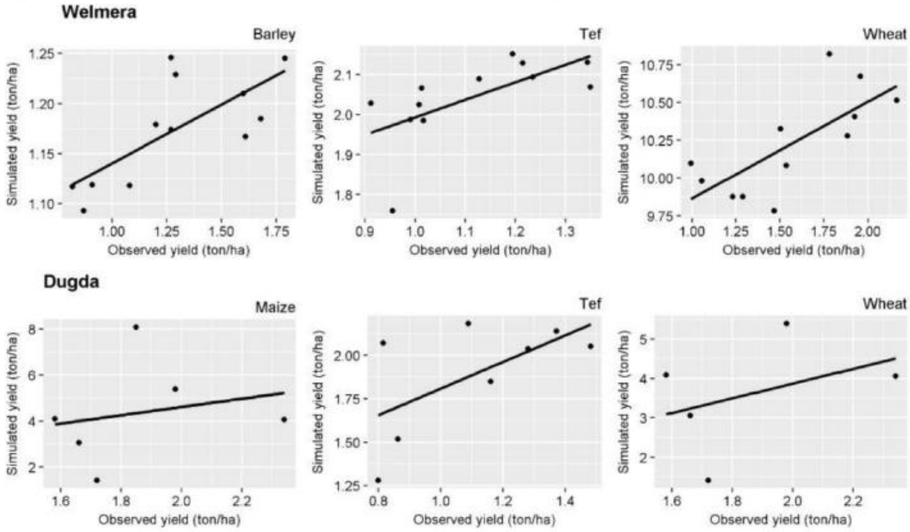
Appendix 1.

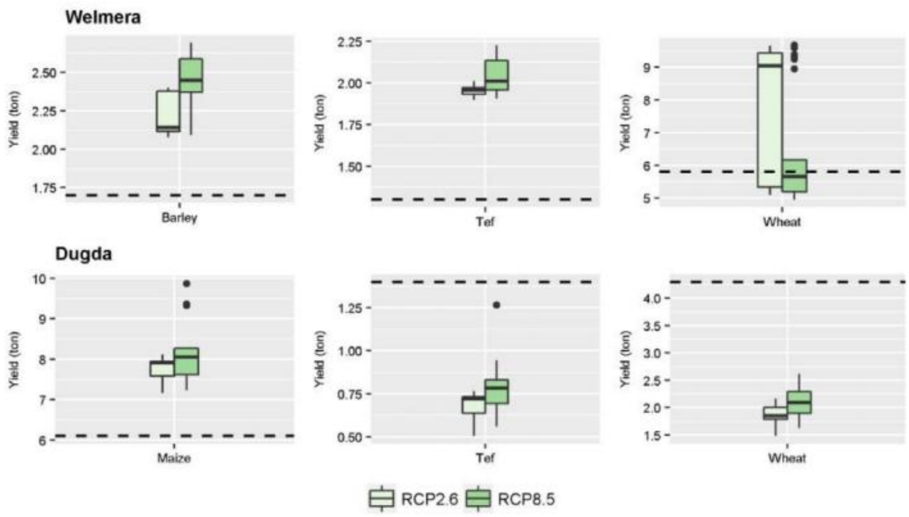
Boxplot showing average daily rainfall, average maximum-and minimum temperature as projected by MarkSimGCM under the two RCPs under the ensemble of 17 GCMs. Crossed signs show baseline period average values projected by MarkSimGCM.



Appendix 2. Correlation between statistical and simulated yield data



Appendix 3. Boxplot showing simulated yields under the two RCPs. Dashed line shows baseline perid average yield.



Publication II

Habtemariam LT., Gandorfer M, Kassa GA and Heissenhuber A. 2016. Factors Influencing Smallholder Farmers Climate change Perceptions: a Study from Farmers in Ethiopia. *Environmental Management* 58(2) pp. 343-348, reprinted with permission from Springer Nature

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Lemlem Teklegiorgis Habtemariam, Markus Gandorfer, Getachew Abate Kassa & Alois Heissenhuber

Environmental Management

ISSN 0364-152X
Volume 58
Number 2

Environmental Management (2016)
58:343-358
DOI 10.1007/s00267-016-0708-0

Springer

Environmental Management (2016) 58:343–358
DOI 10.1007/s00267-016-0708-0

Factors Influencing Smallholder Farmers' Climate Change Perceptions: A Study from Farmers in Ethiopia

Lemlem Teklegiorgis Habtemariam[1] · Markus Gandorfer[2] · Getachew Abate Kassa[1] · Alois Heissenhuber[1]

Received: 25 September 2015 / Accepted: 5 May 2016 / Published online: 14 May 2016

Abstract Factors influencing climate change perceptions have vital roles in designing strategies to enrich climate change understanding. Despite this, factors that influence smallholder farmers' climate change perceptions have not yet been adequately studied. As many of the smallholder farmers live in regions where climate change is predicted to have the most negative impact, their climate change perception is of particular interest. In this study, based on data collected from Ethiopian smallholder farmers, we assessed farmers' perceptions and anticipations of past and future climate change. Furthermore, the factors influencing farmers' climate change perceptions and the relation between farmers' perceptions and available public climate information were assessed. Our findings revealed that a majority of respondents perceive warming temperatures and decreasing rainfall trends that correspond with the local meteorological record. Farmers' perceptions about the past climate did not always reflect their anticipations about the future. A substantial number of farmers' anticipations of future climate were less consistent with climate model projections. The recursive bivariate probit models employed to explore factors affecting different categories of climate change perceptions illustrate statistical significance for explanatory variables including location, gender, age, education, soil fertility status, climate change information, and access to credit services. The findings contribute to the literature by providing evidence not just on farmers' past climate perceptions but also on future climate anticipations. The identified factors help policy makers to provide targeted extension and advisory services to enrich climate change understanding and support appropriate farm-level climate change adaptations.

Keywords Agriculture · Climate change · Perception · Recursive bivariate probit model

Introduction

As scientific evidence shows, warming of the climate system is unequivocal and the contribution of human activity to climate change is significant (IPCC 2013). The perception and understanding of climate change by non-experts has been a topic of interest for researchers and policy makers. As the findings from such studies suggest, not all people perceive and understand the occurrence of climate change, its anthropogenic causes, and the risk it poses (Arbuckle et al. 2013; Buys et al. 2012; Prokopy et al. 2015). The fact that climate change perception varies among people suggests the importance of understanding the source of this variation. Perception is important because it influences the motivation to take action (Grothmann and Patt 2005) as well as the policy-formulation context for actions against climate change (Leiserowitz 2006). Thus, enriching accurate understanding of climate change among people is an essential component of dealing with the climate change problem. For this, insights regarding what influences climate change perception may provide useful information for policy makers to design targeted strategies (Milfont et al. 2014). By identifying the factors that relate

✉ Lemlem Teklegiorgis Habtemariam
leliamsal@yahoo.com

[1] Chair of Agricultural Production and Resource Economics, Technische Universität München, Alte Akademie 14, Freising, Germany

[2] Chair of Economics of Horticulture and Landscaping, Technische Universität München, Alte Akademie 16, Freising, Germany

to climate change perceptions and reaching targeted individuals, policy makers can effectively use resources to minimize the gap in climate change perceptions.

Most of the empirical research that assesses the source of variation in climate change perception is conducted on the general public of developed countries. Despite the existence of several studies that provide descriptive statistics on smallholder farmers' climate change perceptions in developing regions, attempts with regard to the identification and analysis of factors affecting their perception are relatively few. Roco et al. (2014) in Chile, Deressa et al. (2011) in Ethiopia, Silvestri et al. (2012) in Kenya, and Gbetibouo (2009) in South Africa are among the limited studies that attempt to identify the various factors that influence farmers' climate change perception. These studies have focused only on farmers' perceptions on past climate trends providing little attention to what farmers anticipate regarding future climate change. Farmers' future expectations can have a significant role in farming decisions related to climate change. For example, adaption measures that require long-term planning can be subjected to a farmer's future expectations.

As climate change is expected to significantly affect the smallholder farming system prevailing in developing countries, understanding farmers' climate change perceptions and influencing factors is critical for addressing the challenge. To this end, this study investigates Ethiopian smallholder farming communities' climate change perceptions and influencing factors. The study aims at identifying factors that relate to farmers' perceptions and establish linkages between farmers' perception and recorded local meteorological data. Apart from assessing farmers' perceptions on the past climate trend as in previous studies, we investigate farmers' anticipation of a future climate, an issue not explicitly addressed in previous studies. We specifically examine if perception of past climate trends and anticipation of the future climate change are influenced by similar sets of factors for better understanding of farmers' perception. In addition, we investigate the experiences of farmers in relation to crop productivity and whether changes in crop productivity are attributed to climate change. Such information may yield important insights regarding farmers' attitudes toward the impact of climate change. The findings of this study provide important information to enrich academic and policy discourse on climate change perceptions, associated perceived risks, and relevant climate change interventions. The remaining part of the paper is organized as follows: first we provide an overview of existing literature evidence on climate change perception and the determinants. The next part describes the materials and methods we used. Then the result and discussion part is provided followed by the conclusion.

Climate Change Perception and Influencing Factors

It is recognized that people often rely on climate experts and social media outlet information to form judgment about the global climate change phenomenon (Weber 2010). Alternatively, as climate change manifests locally in a way detectable by local people in some parts of the world (Hansen et al. 1998), people may also personally experience changes in their local climate (Krosnick et al. 2006). However, for various reasons, perceptions of climate change may vary among people. First, not everyone has equal access to climate change information, and in the absence of reliable information, people may fail to perceive climate change. In addition, even if information is accessible, as individuals have different cognitive skills, some may be unable to accurately analyze available information (Krosnick et al. 2006). Second, with respect to local climate change, the natural day-to-day variability of the weather can make it difficult for some people to detect long-term local changes (Akerlof et al. 2013), leading to divergent perceptions of climate change. Third, despite being exposed to similar information and experiences, individuals may perceive climate change in different ways (Broomell et al. 2015) as the economic, environmental, cultural, and political implications of climate change are not uniform (Kahan et al. 2011; Weber 2010). The implications of climate change vary according to the socio-economic, demographic, geographical, political, and other conditions of individuals. Hence, these factors reflect the fact that climate change perception can vary depending on these individual-level characteristics and geographical variations.

Previous studies have found some links between these variables and climate change perceptions of the general public as well as various stakeholders involved, including agricultural producers. There are numerous reasons why the farmers' perceptions are particularly relevant and often need to be specifically addressed. Agriculture is naturally sensitive to climate-related changes, which, in turn, directly affects producers. Therefore, farmers are presumably more concerned about climate change than the general public. Furthermore, the limiting factors farmers face in the agriculture sector in general and in their region in particular are unique; there is a need for special recognition in conceptualizing farmers' climate change perceptions (Niles et al. 2015). In addition, as farmers closely work with day-to-day weather situation, they have better potential to detect local changes and impacts (Howe and Leiserowitz 2013) that may influence their perceptions. In these regards, it is expected that farmers from the developed and developing regions that operate in different economic, cultural, political, and environmental conditions conceive climate change differently.

Most of the empirical research conducted in developed regions assess the perception of farmers in regard to the occurrence, causes, and risks of climate change (Arbuckle et al. 2013; Battaglini et al. 2009; Eggers et al. 2015; Niles et al. 2013; Prokopy et al. 2015). Farmers' climate change perceptions have been linked to various factors that influence perceptions. For example, Liu et al. (2014) assessed the perception of ranchers and farmers in the USA regarding the occurrence and causes of climate change. Liu et al. (2014) have linked perception with ideology, political affiliation, and gender. Theory suggests that ideology affects perception by filtering information processing and that individuals tend to perceive climate change in a way that fits with their ideology (Dunlap and McCright 2008; Krosnick et al. 2006; McCright and Dunlap 2011). Arguments on the role of gender come from various perspectives. For example, there is the perspective that men are more exposed to the scientific dimensions of society and that women are more concerned about environmental issues that threaten their families and communities (Liu et al. 2014). Eggers et al. (2015) studied German farmers' perceptions on the risk of climate change regarding their agricultural production and found farming style to be an important variable governing farmers' perceptions. They found traditionalist farmers, often with limited resources, to reject the idea of climate change (Eggers et al. 2015).

In the context of developing countries farmers, empirical studies have focused on identifying the various factors that relate to farmers' perceptions of long-term local climate changes. For instance, the study by Silvestri et al. (2012) assessing the perception of agro-pastoral farmers from Kenya linked perception regarding long-term changes in temperature, rainfall, and rainfall variability with farming experience, access to extension services, food or other aid, and information on livestock production. Similarly, in their assessment of Ethiopian farmers' perception regarding local temperature and rainfall changes, Deressa et al. (2011) identified age, wealth, knowledge of climate change, social capital, and agro-ecological settings to be related with perception. The literature suggests that age or farming experience counts because longer attachment to a place can facilitate recognizing environmental changes, with older people having accumulated knowledge of local conditions (Akerlof et al. 2013; Liu et al. 2014). Income is linked to perception as it determines the capacity to accommodate and respond to change (Semenza et al. 2008). In addition, previous information on climate change may influence local climate change perception through the process of motivated reasoning (Howe and Leiserowitz 2013), implying that individuals with prior information about climate change are likely to perceive changes in the local climate. Similarly, the agricultural extension service, a main technology and information dissemination channel in many rural farming systems, may influence perceptions, as access to information determines farmers' behavior in many farming situations (Adesina et al. 2000). Another study from Chile also found farmers' perceptions regarding long-term local climate changes to be influenced by age, education, income, land tenure, access to meteorological information, and location (Roco et al. 2014). A study by Gbetibouo (2009) that assessed farmers in South Africa linked farmers' perceptions of temperature and rainfall changes with education, farming experience, soil fertility, access to irrigation water, access to climate information and extension services, and location. Theoretically, education or cognitive skills are hypothesized to affect perception by altering the potential of individuals to acquire and retain information (Goebbert et al. 2012; Krosnick et al. 2006). Soil fertility represents natural capital and may relate with perceptions by moderating farmers' sensitivity to environmental changes and thereby affecting their judgments about climate change. Location or agro-ecological settings matter because both real climate trends and limiting climatic conditions to one's livelihood can influence perceptions (Hamilton and Keim 2009; Howe and Leiserowitz 2013).

Overall, the literature suggests that a broad array of variables affect perceptions on climate change by affecting-access to climate change information, information acquiring and retention capabilities, and judgments. The studies show that variations in factors affecting farmers' perceptions of past climate across locations; however, a still critical issue to assess is farmers' future climate anticipations and to investigate whether similar factors influence the perception of past climate and anticipation of future climate. It is important to address this gap because past climate is an event which is already observed, whereas future climate involves some uncertainty in its occurrence. As a result, the variables that affect the two may vary, and by only assessing past climate perception, we may miss important variables relevant to future climate perception. The findings of our study contribute to the literature by providing evidence not just on farmers past climate perceptions but also on future climate anticipations. For policy makers, this is crucial to design informed approach to increase climate change concern.

Materials and Methods

Study Area

The study was conducted in Ethiopia, one of the countries most vulnerable (Mideksa 2010; Robinson et al. 2012) to climate change with observed (Tadege 2007) and projected (Conway and Schipper 2011) changes in climate. Smallholder farming is the dominant livelihood system in the country. The study used data collected in Dugda and Welmera districts. Dugda district is located in the semi-arid rift valley area of central Ethiopia. The area is characterized by higher temperatures and erratic rainfall, for example, long-term rainfall data from the area displayed in Fig. 1 shows a proportion of 62 % negative anomaly with a standard deviation of about 100 mm for the negative anomaly and 92 mm for the positive anomaly, respectively. The Welmera district is situated at higher altitudes and receives relatively higher rainfall than Dugda. Small-scale subsistence mixed farming system, where farmers' livelihood depends on crop and livestock production, is a common practice in both districts. Cereals, such as wheat, *teff*, barley, and maize, are major crops commonly grown in the region. Cereal production is mainly rainfed, low input, and the use of mechanized agriculture is rare. Unlike the Welmera district, where irrigated vegetable production is restricted to small areas in the backyards of households, farmers in some parts of Dugda produce irrigated vegetables on a comparatively larger scale. The districts are not exceptional with respect to the widely recognized farming problems of Ethiopia, such as scarcity and expensive inputs, limited market and credit access, soil fertility problems, growing population pressures, and weak extension services (Davis et al. 2010; McIntosh et al. 2013).

Data

Face-to-face interviews were conducted from November 2012 to February 2013 using a structured questionnaire comprising both open- and close-ended questions. Respondents were randomly selected from six peasant associations (the lowest administrative unit) located in the two districts. Fifty households were selected from each peasant association, making a total of three hundred samples. When it was impossible to interview the selected household, the next available household was included in the sample. In this manner, the total number of households interviewed remained at 300, but there were some

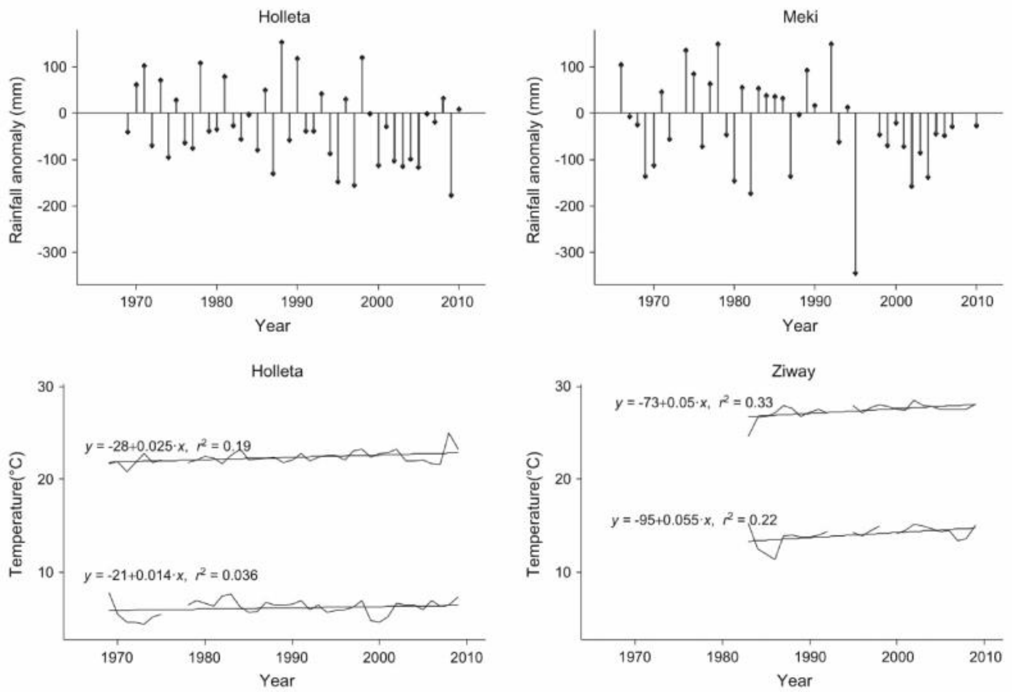

Fig. 1 *Kiremit* rainfall anomalies calculated based on 1969–1990 and 1966–1990 reference years for Holleta (2400 m.a.s.l) and Meki (1680 m.a.s.l) stations, respectively; maximum and minimum temperature trends at Holleta and Ziway (1640 m.a.s.l) stations. *m.a.s.l* meter above sea level

respondents who preferred not to answer some of the questions. This has led to questionnaires that are incomplete in some aspects. Altogether 182 respondents that provided full information on all the variables relevant for this study are included in the analysis. Since nearly all respondents have provided information on key demographic variables such as age, gender, and education, we were able to compare the retained sample (i.e., the one included in the analysis) to the rest in terms of these key variables. The results indicate that there is no significant difference between the two groups with respect to these key variables. Therefore, we assume that there is no systematic bias and the retained sample remains representative of the larger sample.

The questionnaire covered a wide range of issues including information on socio-economic background, production data, and perception of climate change and adaptation measures. In line with the objectives, this paper focuses on those parts of the questionnaire that have relevance to the issue of farmers' perceptions of climate change and related impact. Table 1 presents the specific perception related questions used for this analysis.

In addition to the household-level data, this study also used recorded, long-term local meteorological data to analyze changes in the local climate. For this, the available long-term monthly rainfall as well as minimum and maximum temperature records were obtained from weather stations located within or close to the study districts. Temperature and rainfall data for the Welmera district were obtained from Holleta station, located in the district. The station found in Dugda (i.e., Meki) records only rainfall. Therefore, temperature data were obtained from Ziway station, located in a neighboring district at a distance of about 27 km from Meki. The Ziway station is situated roughly at the same elevation as Meki (approximately 1640 m.a.s.l), and the area is characterized by similar terrain and agro-ecology. The available meteorological data covered the time period 1969–2010 for Holleta, 1966–2010 for Meki, and 1983–2010 for Ziway stations. After excluding those years with more than one month of missing value, the length of available station records span from 24 years in case of Ziway to 31 and 39 years in case of Meki and Holleta stations, respectively. The monthly maximum and minimum temperature data from the meteorological stations were averaged to find annual average values. Maximum and minimum temperature records were assessed for linear trends at both stations by regressing temperature data on time. The statistical significance of the trends was then determined by a t test. For rainfall analysis, total *Kiremit* rainfall (the main cropping season spanning June to September), which contributes the majority of the annual total, was considered. Rainfall anomalies were calculated as a deviation from the mean of 1969–1990 and 1966–1990 reference period for Holleta and Meki stations, respectively. These reference periods lie within the current normal climate period as defined by the World Meteorological Organization (i.e., a thirty-year climate average of the 1961–1990). However, due to lack of recorded data for the periods in the early 1960s, the total numbers of years in the reference period are shorter than thirty years. We considered the years after 1990 to come up with a reference period of 30 years to examine potential underrepresentation of the climate variability that may arise from using less than 30 years reference period. However, we found only a small magnitude change in average values without any impact on the general trend that was obtained using the shorter reference period which lies within the standard climate normal period.

Methods and Model Specifications

Based on long-term local temperature and rainfall records, and published climate change studies, we established four categories of climate change trends (i.e., past rainfall, past temperature, future rainfall, and future temperature). As indicated in Fig. 1, the general trend of long-term meteorological data shows increasing temperatures and decreasing rainfall in both study districts. Regarding future climate, climate models consistently project future warming for the country (Conway and Schipper 2011). Climate model projections on rainfall are inconsistent and sub-national differences exist in the size and direction of change (Conway and Schipper 2011). Findings from studies that have assessed current rainfall trend in different parts of the country also show the sub-national difference in size and magnitude of rainfall trend that is already being observed (Viste et al. 2013). Since the recent past trend of rainfall in the study area suggests decreasing trend, we establish the trend of the future rainfall based on this evidence.

In the questionnaire, farmers' perceptions on past climate trend and future expectations are recorded as categorical data as it is presented in Table 1. For our analysis, the categorical variables of past climate perceptions and future climate anticipations are converted to binary variables to assess factors that relate to perceptions that align with historical meteorological data evidence and climate model projections. The binary perception variables are thus created to represent whether the individual has perception that aligns with the evidence on the four categories of perception as follows:

1. whether a farmer perceives a decreasing trend in past rainfall,
2. whether a farmer perceives an increasing trend in past temperature,

Table 1 Questions that addressed respondents' perception

Questions	Answer options
Observed long-term change in the amount of *Kiremit** rainfall in the past 15 years?	❑ Yes ❑ No ❑ I don't know
	If yes, ❑ Increased ❑ Decreased
Observed long-term shift in the onset of *Kiremit* rainfall in the past 15 years?	❑ Yes ❑ No ❑ I don't know
	If yes, ❑ Begins late ❑ Begins early
Observed long-term shift in the ending of *Kiremit* rainfall in the past 15 years?	❑ Yes ❑ No ❑ I don't know
	If yes, ❑ Stops early ❑ stops late
Observed long-term change in temperature in the past 15 years?	❑ Yes ❑ No ❑ I don't know
	If yes ❑ Increased ❑ Decreased
What changed the rainfall and temperature?	Open question
Changes you anticipate in the future regarding rainfall and temperature?	❑ Increase in temperature
	❑ Decrease in temperature
	❑ No change in temperature
	❑ Increase in rainfall
	❑ Decrease in rainfall
	❑ No change in rainfall
	❑ I don't know
Changes you observed in crop productivity in the past 15 years, indicate for the five major crops you grow	❑ Increasing
	❑ Decreasing
	❑ Varies
	❑ No change
	❑ I don't know
If increasing or decreasing, reasons (*follow-up question*)	❑ Rainfall change
	❑ Temperature change
	❑ Management
	❑ Input
	❑ Improved seed
	❑ I don't know
	❑ Others, specify

*Kiremit** the main rainy season in Ethiopia

3. whether a farmer anticipates a decreasing future rainfall, and
4. whether a farmer anticipates an increasing future temperature.

We investigate how a set of demographic, economic, climate knowledge, agro-ecological, and other relevant variables influence farmers' perceptions on each category of climate change. The response variables are the binary perception variables on the four categories of climate change. In selecting the explanatory variables for the analysis, we have considered the variables discussed in the literature review section and data availability. Apart from previously identified explanatory variables, we additionally assessed whether recent experience on agricultural production shock and access to credit services relates to climate change perception. Agricultural production shock here refers to shocks that have affected the farm in the recent past such as flooding, drought, and disease and pest outbreak. In their study of climate change risk perception, Leiserowitz (2006) show that affective images of climate change influence climate change risk perception due to the role affect plays in subsequent rational thought. In other words, recent vivid and concrete negative memories have influence on perception. Therefore, we assess whether recent experience on production shock is associated to farmers perception. Access to credit services is expected to affect perceptions, as it determines a financial capital that can moderate sensitivity to climate change impact. We hypothesize that farmers' perceptions relate to demographic, economic, climate change knowledge, and agro-ecological variables. We also hypothesize that recent experience of extreme events and credit service access influence perceptions of long-term climate change.

The specific explanatory variables included in the model are geographical location (district), gender, age, education, income from agricultural sell, soil fertility status, farm size, information on climate change, recent experiences on agricultural production, and access to credit services. Table 2 shows the questions related to the independent variables included in the analysis and descriptive statistics of the samples, while Table 3 shows the description of the explanatory variables used in the analysis, the coding used in the analysis, and the expected effects of the variables.

We have the following general functional relationship to identify factors that influence each perception category:

$$\begin{aligned}\text{Perception}_i = F_i(&\text{district}_i, \text{gender}_i, \text{age}_i, \text{education}_i,\\ &\text{agricultural sell}_i, \text{soilstatus}_i, \text{farm size}_i,\\ &\text{climate change}_i, \text{shocks}_i, \text{credit service}_i).\end{aligned}$$

The simple probit model along with logit model is commonly used to model a binary (1/0) response variables. The models estimate the probability that $y = 1$ as a function of the independent variables hypothesized to influence the outcome:

$$p = \Pr[y = 1|X] = F(X'\beta). \quad (1)$$

However, the standard probit and logit models lead to biased estimates if the model contains an endogenous variable. Among the explanatory variables in this study, the variable 'information on climate change' that documents whether the farmers previously received climate change information is suspected to be endogenous. As receiving climate change information is choice-based variable, farmers who receive climate change information might have unobserved characteristic that is related with perception. Or we may assume that individuals who perceive climate change could likely be the one to seek or receive climate change information leading to reverse causality. Other explanatory variables such as farm size that are treated to be endogenous in some cases are less likely to be endogenous in the context of the agricultural system where

Table 2 Questions that addressed the independent variables included in the analysis and descriptive statistics of the samples

Questions	Answer options	Proportion or mean (SD*)		
		Welmera	Dugda	Total
Gender	❑ Male	0.80	0.83	0.80
	❑ Female	0.20	0.17	0.20
Age	In number	45.7 (14.3)	42.3 (12.4)	44.9 (13.9)
Formal education	❑ None	0.52	0.26	0.46
	❑ Primary	0.36	0.61	0.42
	❑ Secondary	0.11	0.11	0.11
	❑ Post-secondary	0.01	0.02	0.02
Agricultural sell	Value in Birr*	2919 (3363)	8118 (5739)	4159 (4610)
Farm size	Amount in hectare	1.33 (0.99)	1.76 (0.88)	1.4 (0.9)
Soil fertility	❑ Very fertile	0.02	0	0.02
	❑ Fertile	0.82	0.96	0.85
	❑ Infertile	0.16	0.04	0.13
Received climate change information?	❑ Yes	0.69	0.72	0.69
	❑ No	0.31	0.28	0.31
Identify shocks that affected your farm in the past 15 years and specify the year	Percent presented here indicates those respondents who reported experiencing at least one type of shocks in the two years period preceding interview	0.51	0.76	0.57
Do you get credit service?	❑ Yes	24.8	56.5	32.5
	❑ No	75.2	43.5	67.5
Receive agricultural extension service?	❑ Yes	0.88	0.89	0.88
	❑ No	0.12	0.11	0.12

*Birr** Ethiopian currency

*SD** Standard deviation

Table 3 Description of variables used in the perception models and hypothesized effects

Variable	Description	Expected effect
Dependent variable		
Perception on past rainfall	Dummy variable = 1 if the respondent perceives decreasing rainfall trend in the past and 0 otherwise	
Perception on past temperature	Dummy variable = 1 if the respondent perceives increasing temperature trend in the past and 0 otherwise	
Anticipation of future rainfall	Dummy variable = 1 if the respondent anticipates decreasing rainfall in the future and 0 otherwise	
Anticipation of future temperature	Dummy variable = 1 if the respondent anticipates increasing temperature in the future and 0 otherwise	
Explanatory variables		
District	Dummy variable = 1 if the respondent lives in Welmera district and 0 otherwise	(−)
Gender	Dummy variable = 1 if male otherwise 0	(−)
Age	Age of respondent (categorized into four quartile age groups, coded 1 = 1st quartile (ref.) - 4 = 4th quartile)	(+)
Education	Educational level (categorical coded 1 = None(ref.), 2 = Primary, 3 = Secondary, 4 = Post-secondary)	(+)
Agricultural sell	Household crop sell for the cropping season 2012/2013 in Birr (continuous)	(−)
Farm size	Farm size in Hectare (continuous)	(−)
Farm soil fertility status	Soil fertility status (categorical coded 1 = very fertile, 2 = fertile, 3 = infertile(ref.))	(−)
Climate change information	Dummy variable = 1 if the respondent had received climate change-related information from any sources previously and 0 otherwise	(+)
Shock	Dummy variable = 1 if the respondent experienced natural production shock in the two years preceding our survey, and 0 otherwise	(+)
Credit service	Dummy variable = 1 if the respondent gets credit service and 0 otherwise	(−)
Agricultural extension	Dummy variable = 1 if the respondent receives extension service from any source, and 0 otherwise	

Birr = Ethiopian currency

Ref. = reference category

the present study is conducted. For example, as sale and exchange of land is prohibited according to the country's land policy, farm size in our context is not an endogenous decision made by the farmer. For similar reason, the soil status variable that describes the fertility status of the randomly distributed land is less likely to be endogenous. Education can be treated as exogenous to present-day climate change perception as it is a choice made far back in the past. In the rural part of Ethiopia with a nearly full absence of other economic activities, farm income generation activity is not a choice to be made by households. In addition, the characteristics that affect agricultural sell are not expected to relate with climate change perception. The variable on recent experience of production shock mainly refers to exogenous natural shocks as a result of weather-related changes. Although participating in credit services is normally a choice-based variable, there is compelling reason that makes it less likely to be endogenous in our context. For example, in the study areas, formal credit services are provided mainly through group guarantee schemes suggesting that participation in credit service is mainly a result of how much a farmer is trusted by other farmers to become a group member, and we assume this characteristic that determines participation is not related to perception.

Therefore, in addition to the simple binary probit model, we applied the recursive bivariate probit model to handle endogeneity issue in the binary explanatory variable 'climate change information.' The recursive bivariate probit model is a simultaneous equation model building from two equation framework in which one equation represents reduced form equation for the potentially endogenous dummy variable, whereas the second equation represents structural form equation determining the outcome of interest (Marra and Radice 2011). The second equation includes a binary dependent variable of the first equation as endogenous explanatory variable. The recursive bivariate probit model is applied in this study by estimating two equations: one for the perception categories and a second for the endogenous variable climate change information.

Let p_i be the probability to perceive climate change and cc_i be the endogenous binary variable representing the probability to receive climate change information. The p_i and cc_i can be modeled as a recursive bivariate probit model based on latent variable formulations of p_i^* and cc_i^* as follows:

$$p_i^* = \beta' x_i + \gamma cc_i + \varepsilon_1, \quad p_i = \begin{cases} 1 & \text{if } p_i^* > 0 \\ 0 & \text{otherwise} \end{cases}. \tag{2}$$

x_i includes all the exogenous covariates (i.e., district, gender, age, education, agricultural sell, soil status, farm size, shocks, and credit services). The cc_i represents the endogenous explanatory variable climate change information:

$$cc_i^* = \alpha' z_i + \varepsilon_2, \quad cc_i = \begin{cases} 1 & \text{if } CC_i^* > 0 \\ 0 & \text{otherwise} \end{cases}. \tag{3}$$

z_i represents the exogenous explanatory variables district, gender, age, education, and a variable that represents whether the individual receives agricultural extension service as instrument.

Equations 2 and 3 are estimated simultaneously by maximum likelihood method. The error terms ε_i and ε_2 are assumed to be distributed bivariate normal with correlation ρ. If statistical test shows that $\rho = 0$ we assume that there is no problem of unobserved confounding and the two equations may be estimated separately by simple probit model. If $\neq 0$, the suspected explanatory variable is assumed to be endogenous and bivariate model is more efficient than simple probit model. To avoid model parameter identification problems, Maddala (1983) suggests to meet exclusion restrictions in recursive bivariate probit models; however, others show that exclusion restrictions are not required unless there is too small variation in the data (Wilde 2000). In our study, we added a dummy variable indicating whether the farmer receives agricultural extension service in the reduced form equation as instrumental variable to improve the power of identification.

Results and Discussion

Perceptions of Local Climate Change and Its Causes

Results indicate that approximately 75 % of respondents perceived warming temperatures, and a similar proportion (77 %) perceived decreasing rainfall trends in the past (Fig. 2a). About 87 % of respondents indicated observing late onset of the rainy season, and 79 % indicated observing early cessation (Fig. 2b). When asked to anticipate changes in future rainfall and temperature, only 45 and 37 % of respondents anticipated increasing future temperature and decreasing rainfall, respectively (Fig. 2c). Contrary to perceptions shared by the vast majority of respondents on past temperature and rainfall trends, farmers' opinions on future climate conditions were relatively divided. A number of respondents also replied "I do not know" when asked to predict future climate, showing that they cannot make assumption about the future. These farmers have often noted that anything can happen in the future with the will of God. With regard to the question of the causes of perceived temperature and rainfall changes, the majority (67 %) of respondents believe that the changes are due to continuous deforestation in the area (Fig. 2d). Some respondents linked the changes to a divine act or described the changes as unexplainable, whereas nearly a fifth of respondents stated that they had no idea about the cause.

Previous studies from Ethiopia and other countries in the region have reported similar findings regarding farmers' perceptions of warming temperatures and decreasing rainfall trends in past years (Deressa et al. 2011; Gebrehiwot and Veen 2013; Silvestri et al. 2012). However, the percentage of farmers that reported observing increasing temperatures and decreasing rainfall is higher than the percentage found by (Deressa et al. 2011) that assessed Ethiopian farmers based on a data collected in 2004–2005. This may be because our data were collected more recently, and within that timeframe, farmers may have become more aware of local changes. Another possible reason documented in the literature is that the climate change belief of people may change depending on recent climate experiences, for example, weather during data collection period (Schwartz 2012). Compared with studies from the developed world, the percentage of farmers that perceived changes in the climate is less than that reported by Battaglini et al. (2009) for European farmers, but higher than farmers' perception regarding the occurrence of climate change as reported by Prokopy et al. (2015) for farmers from the USA, Australia, and New Zealand. Apart from changes in rainfall and temperature, farmers have also indicated observing changes regarding the timing of rainfall that plays an important role in many agricultural production activities.

With respect to the future climate, the prediction of future warming is supported by climate model projections that predict increasing temperature trends across the country. For instance, future climate change projections over Ethiopia show a multi-model average annual warming of 1.2 °C by the 2020s and 2.2 °C by the 2050s (Conway and Schipper 2011). However, climate model projections on rainfall show high model uncertainty in which some predict an increasing trend, while others suggest decreasing rainfall across the country (Conway and Schipper 2011).

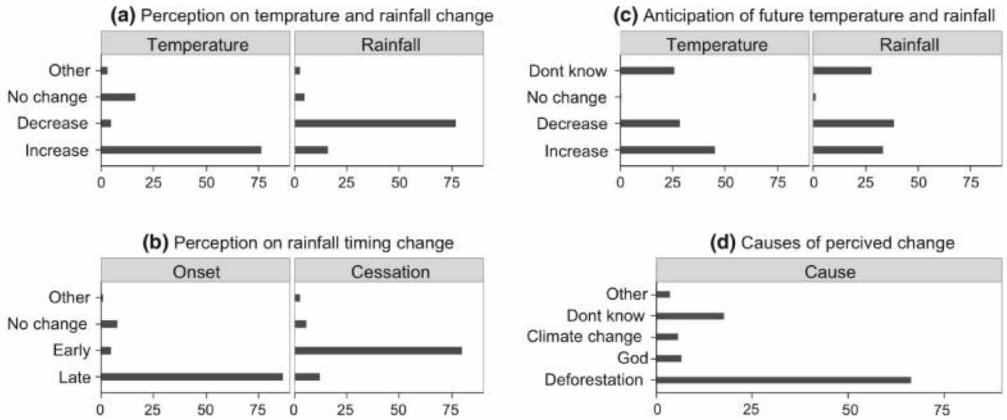

Fig. 2 Percentage of respondents on **a** perception of past temperature and rainfall change; **b** anticipation of future temperature and rainfall; **c** perception of change in the rainy season timing; **d** perspective on the causes of perceived climatic changes

Examining the percentage of farmers regarding past climate perception versus future anticipation, one can assume that what farmers perceive about the past climate does not necessarily reflect what they expect about the future climate. Regarding the causes of climate changes, findings from the studies of Nyanga et al. (2011) in Zambia and Mude et al. (2007) in Kenya reflect similar deforestation- and supernatural-related farmer explanations on the causes of climate variability and change. Deforestation is a widespread problem in many parts of Ethiopia, including the study areas. As previously noted, farmers believe that deforestation is the main cause behind perceived climate changes.

Evidence from meteorological records

The recorded local meteorological data analyzed to ascertain farmers' perception showed agreement with farmers' perceptions of increasing temperature and decreasing rainfall trends (Fig. 1). A statistically significant increasing trend has been found using the annual average maximum (at $P < 0.01$) and minimum temperature (at $P < 0.05$) records from Ziway station. Annual average maximum temperature records from Holleta station also show an increasing trend significant at $P < 0.01$. However, the increasing trend in annual minimum temperatures from Holleta station is not statistically significant. The *Kiremit* rainfall anomaly pattern shows below average rainfall for most years of the past decade, at both Holleta and Meki stations (Fig. 1). Rainfall anomaly was calculated based on 1969–1990 and 1966–1990 reference years for Holleta and Meki stations, respectively. Analysis of total *Kiremit* rainfall indicates a decreasing trend significant at $P < 0.1$ at both stations.

Increasing temperature trends were also observed in other studies from Ethiopia (Gebrehiwot and Veen 2013; Kassie et al. 2013). At the national level, Tadege (2007) found a warming trend in national average annual minimum temperatures over the past 55 years by about 0.37 °C every ten years. Regarding rainfall trend, other studies from Ethiopia documented mixed patterns in which some studies found a downward trend similar to our finding (Gebrehiwot and Veen 2013; Kassie et al. 2013; Meze-Hausken 2004; Viste et al. 2013).

Perceived Effects of Climate Change on Crop Yield

To identify whether farmers perceived the effect of climate change on crop yield, we asked respondents to indicate their experience on crop yield trends in the past fifteen years and to share their opinion on what caused yield change. It is expected that crops will respond differently to rainfall and temperature changes. As a result, respondents were requested to share their evaluation of crop yields for each crop they grow separately, to better understand the relationship between the varying meteorological variables and the crop output. Most farmers grow a combination of crops, often more than two. It was found that farmers' perceptions regarding the effects of climate change varied with the crop in question. Figure 3a, b exclusively summarize the results for climate-related reasons. The majority of farmers producing wheat, barley, and potato indicated experiencing improving yield trend and believed that non-climate-related factors such as improved seed and better

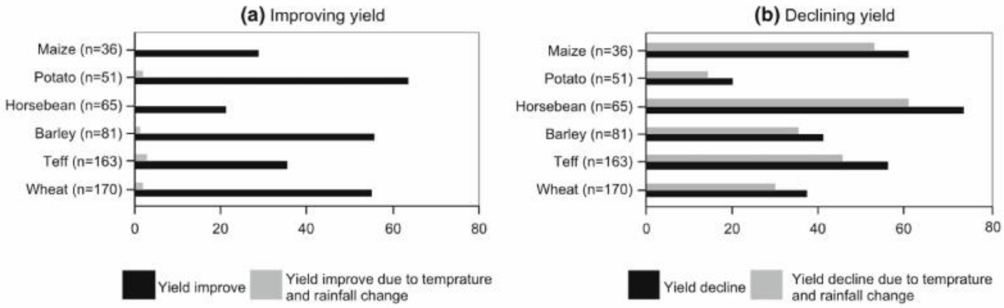

Fig. 3 Illustration of the percentage of farmers who experienced yield **a** improve, and, **b** decline in the indicated crops. And the percentage of those who attributed the yield change to climatic factors. *n* number of respondents

production technologies contributed (Fig. 3a). Figure 3b illustrates that most farmers producing *teff*, maize, and horse bean have reported observing a declining yield trend and believe that yield reduction is mainly caused by climatic changes.

Perceiving temperature and rainfall changes as the reasons for declining yield trend may influence farmers' decisions to adapt. Some of the results also suggest that farmers' perceptions regarding the impact of climate change may be associated with access to agricultural technology. There is a tendency that yield reduction is associated with climate change on crops with lesser-improved seed access, either in terms of availability or affordability. For example, in the study areas, farmers have better access to improved wheat seed than improved *teff* (Spielman et al. 2011), or in case of maize farmers often find it unaffordable to buy hybrid maize seed every cropping year. If accessible agricultural technologies such as improved seed increases yield over conventional ones, farmers seem to perceive less climate change-related effects. This may be particularly relevant in areas that are newly implementing technology-intensive agricultural systems; farmers in these areas may underestimate the effects of climate change. A declining yield trend due to climate change has been reported by farmers in other areas too (Roco et al. 2014).

Factors Affecting Farmers' Climate Change Perceptions

A summary of the result of the simple probit models and the recursive bivariate probit models are shown in Tables 4 and 5. Overall, the two approaches resulted similar outcome. A Wald test of $\rho = 0$ suggests that the variable climate change information is endogenous to perception of past temperature and rainfall. However, climate change information is not found to be endogenous to perception of future temperature and rainfall. The use of recursive bivariate probit model is, therefore, necessary for the cases in which the variable climate change information is found to be endogenous. We base our discussions on the significance of variables based on the outputs of the recursive bivariate probit model for all the climate change perception categories.

Overall, the analyses have revealed that while some factors relate to all or most of the different categories of climate change perceptions and anticipations, others were relevant only to a certain category. The positive and significant relationship between many of the perception categories and the explanatory variable "district" implies that farmers from the Welmera district are more likely to perceive decreasing rainfall and increasing temperature in the past and to anticipate a similar trend for the future. The two districts differ in their agro-ecology, i.e., while Welmera is located in a cool highland agro-ecology, Dugda is located in a tepid environment. As shown in Fig. 1, statistical analysis of meteorological data showed more or less similar trends in both districts in regards to past climate. Initially, we assumed that change in climate would be more readily perceived in the Dugda district due to the relatively warmer real temperature and the lower amount of rainfall the district receives. However, our analysis finding contradicts this. A study by Deressa et al. (2011) also reported that farmers from the highland agro-ecological areas are more likely to perceive climate change. Roco et al. (2014) found farmers from an area where meteorological records show higher temperature and rainfall changes to be less likely to perceive climate change. In terms of sample characteristics, in general, the results show that farmers in the Dugda district have better opportunities in terms of farm size, wealth, education, and agricultural services. Apart from this, it is also clear that farmers in Welmera have comparatively less access to irrigation water than their counterparts in Dugda. Some literature suggests that

Table 4 Estimates of simple probit models

Explanatory variables	Past rainfall		Past temperature		Future rainfall		Future temperature	
	Coef.	$P > z$	Coef.	$P > z$	Coef.	$P > z$	Coef.	$P > z$
District	0.645	0.033**	0.510	0.096*	1.080	0.001***	0.665	0.025***
Gender	0.138	0.629	0.404	0.163	−0.572	0.038**	−0.518	0.053*
Age								
Age (35–42)	0.592	0.086*	−0.032	0.918	−0.112	0.712	−0.285	0.332
Age (43–55)	−0.068	0.835	0.552	0.120	−0.142	0.668	−0.404	0.205
Age (>55)	0.145	0.675	0.718	0.049**	−0.267	0.436	−0.386	0.235
Education								
Education (primary)	−0.034	0.892	0.132	0.607	0.611	0.016**	0.435	0.072*
Education (secondary)	0.287	0.511	1.48	0.012**	1.017	0.008***	0.880	0.018**
Education (post-secondary)	0		0		0		0	
Agricultural sell	−0.000	0.640	−0.000	0.568	−0.000	0.130	−0.000	0.157
Farm size	−0.039	0.753	−0.190	0.119	0.056	0.626	−0.025	0.826
Soil status								
Soil status (very fertile)	−0.281	0.740	−0.808	0.357	0		0	
Soil status (fertile)	−0.153	0.666	−0.102	0.767	−0.411	0.188	−0.624	0.046**
Climate change information	0.170	0.521	0.572	0.034**	0.510	0.049**	0.474	0.056*
Shock	0.486	0.043**	0.050	0.840	−0.006	0.978	0.216	0.313
Credit service	0.145	0.579	−0.117	0.652	0.371	0.136	0.426	0.080*
Constant	−0.162	0.784	−0.347	0.555	−1.011	0.088	−0.107	0.845
Pseudo R^2	0.09		0.14		0.16		0.13	
N	180		180		177		177	

NB: The zero values are as a result of the small number observations in these categories that predicted outcome perfectly and the STATA software dropping these observations

*** Significant at $P < 0.01$; ** Significant at $P < 0.05$; * Significant at $P < 0.1$ level

the limiting factor in a region such as water or infrastructure can affect farmers' climate change perceptions and behavior (e.g., Niles et al. 2015). We assume that even though the Welmera district receives better rainfall, less accessible irrigation water, which can be used to grow high cash crops during the dry period, can make farmers more sensitive to climate changes.

The negative coefficient on gender suggests that male respondents are less likely to anticipate a decreasing future rainfall, increasing future temperature and increasing past temperature. Gender showed no significance in past rainfall perception. The finding on gender is in line with the perspective that women are more concerned about environmental issues that threaten their families and communities (Liu et al. 2014). However, this relation was more reflected with regard to future climate anticipations in which men showed less concern about the future climate, and gender played no role in past rainfall perception. This could be because, in past climate perceptions, both women and men had equal chances of observing changes, unlike future climate changes that require further analysis. Other studies have also found that female farmers are more concerned with the impact of climate change (Liu et al. 2014).

The results also indicate that, when compared with respondents in the young age group, farmers in the older age group are more likely to perceive increasing temperature trend over the past years. For past rainfall perception the first age category showed significance but not the older categories. No significant association was found between age and the other perception categories. The age variable relation with perception regarding past temperature is in agreement with our prior expectation, in which we assumed older farmers to be likely more experienced in farming and understanding their environment, enabling them to easily detect changes in climate. This result is contrary to what Roco et al. (2014) found but consistent with Deressa et al. (2011). The natural high seasonal variability of rainfall might have weakened the age effect of perception regarding past rainfall trend. There was no significant relation between future climate anticipation and age, suggesting that age has little relevance for anticipating a phenomenon which has not yet been observed.

Table 5 Estimates of recursive bivariate probit models

Explanatory variables	Past rainfall		Past temperature		Future rainfall		Future temperature	
	Coef.	P > z	Coef.	P > z	Coef.	P > z	Coef.	P > z
District	0.535	0.045**	0.426	0.107	0.986	0.007***	0.658	0.019**
Gender	−0.344	0.163	−0.377	0.099*	−0.886	0.013**	−0.624	0.083*
Age								
Age (35–42)	0.525	0.086*	0.064	0.808	−0.069	0.803	−0.279	0.333
Age (43–55)	−0.234	0.432	0.089	0.770	−0.251	0.442	−0.443	0.182
Age (>55)	0.190	0.554	0.549	0.097*	−0.168	0.616	−0.366	0.286
Education								
Education (primary)	0.050	0.828	0.092	0.686	0.601	0.017**	0.440	0.070*
Education (secondary)	0.336	0.365	0.987	0.006***	1.10	0.001***	0.922	0.009***
Education (post-secondary)	4.851	0.000***	7.935	0.000***	6.65	0.000***	6.52	0.000***
Agricultural sell	−0.000	0.615	−0.00	0.824	−0.000	0.147	−0.000	0.154
Farm size	−0.054	0.612	−0.132	0.211	0.042	0.690	−0.023	0.831
Soil status								
Soil status (very fertile)	−0.265	0.728	−0.411	0.557	−5.70	0.002***	−5.85	0.000***
Soil status (fertile)	−0.102	0.690	0.183	0.327	−0.390	0.143	−0.623	0.046**
Climate change information	1.493	0.000***	2.05	0.000***	1.39	0.056**	0.764	0.281
Shock	0.395	0.068*	0.025	0.903	−0.021	0.919	0.211	0.327
Credit service	0.137	0.521	−0.099	0.525	0.336	0.155	0.422	0.073*
Intercept	−0.693	0.111	−1.12	0.019**	−1.27	0.012**	−0.217	0.728
rho	−0.838	0.001***	−1	0.00***	−0.614	0.40	−0.187	0.68
N	182		182		182		182	

*** Significant at $P < 0.01$; ** Significant at $P < 0.05$; * Significant at $P < 0.1$ level

The variable education has been positively associated with all perception categories. Farmers with post-secondary education were found to be more likely to perceive and anticipate all the changes. However, the number of respondents who are actually included in that category is very small. Farmers with secondary education were found to be more likely to perceiving an increasing temperature trend in the past, anticipating decreasing rainfall, and anticipating increasing temperatures in the future. In the case of anticipation of the future climate, even farmers with primary education were more likely to anticipate the changes than farmers with no education. Farmers with a higher education level are assumed to have better cognition skills, enabling them to better assess what has been observed and make predictions based on observation and information. Thus, the positive relation between most of the different perception categories and education is as expected.

Income from agriculture is not found to be related to any of the perception categories. Regarding the importance of agricultural income on perceptions, previous studies have reported mixed results. For example, while Deressa et al. (2011) and Roco et al. (2014) found a positive relationship for agricultural income, Silvestri et al. (2012) found no relation between farmers' perceptions and farm income.

Farm soil fertility status is another explanatory variable found to be important, but only in anticipating increasing future temperature and decreasing rainfall. As expected, farmers with fertile soil were found to be less likely to anticipate increasing future temperature and decreasing future rainfall in relation to farmers with infertile soil. Farm soil fertility status showed no significant relationship with other perceptions. We expected that having the natural capital of fertile soil would significantly reduce farmers' perception of the past climate and concern for the future climate. However, the effect of soil fertility was found to be significant only in future climate anticipation. Other studies have found that farmers with highly fertile soil are less likely to perceive change in temperature but more likely to perceive change in rainfall (Gbetibouo 2009).

Previous climate change information was found to increase the likelihood of perceiving a decreasing past rainfall, an increasing past temperature trend, and anticipating decreasing rainfall in the future. Some literature suggests that prior knowledge of climate change affects perception through motivated reasoning. The climate change information variable in our analysis also supports this possibility. Farmers with prior knowledge of climate change were significantly different from others in their perceptions. Access to information has also been an important determinant of farmers' behavior in other situations (Adesina et al. 2000).

Farmers who had the most recent experience in production shock might have been influenced to negatively associate with the rainfall trend, as recent experiences on extreme weather events influence perceptions about long-term climate change due to negative associations that play a role in subsequent rational thought (Leiserowitz 2006). Recent experience has not affected other perception categories.

The positive coefficient on credit services suggests a higher probability of farmers with credit services to anticipate increasing future temperatures. Participation in credit services have shown no significant link with past climate perceptions. In contrast with our initial assumption, farmers who participate in credit services were found more likely to be concerned about the future. Initially, the assumption was that farmers with credit service have better financial capital to use technological progress and withstand the impacts of climate changes and would, therefore, be less likely to perceive climate change. However, these respondents could also be farmers who plan to invest in their farms and who are concerned about the risk of losing capital due to unforeseen changes.

Conclusion and Policy Implications

Using household data collected from smallholder farmers in Ethiopia, we assessed farmers' perceptions of climate change and the factors affecting perception. We found that a majority of farmers in the study area perceived changes in the local temperature and rainfall conditions that correspond with the local meteorological record. However, less than half of the respondents anticipated a future temperature change consistent with climate model projections. Our finding also suggests that farmers' perceptions about the past climate do not necessarily reflect what they anticipate about the future climate. Farmers' perceptions appear to be affected by a number of factors. While some factors influence both the perception of past climate and anticipation of future climate, others influence only one of these aspects. Often climate change was perceived to be the reason behind declining yield in crops; however, an important difference was noticed in terms of perception on the impacts of climate change on crop productivity that appear to drive from difference on access to agricultural technology of crops. The geographical area where the farmer lives, gender, age, education, farm soil fertility status, climate change information, recent experiences, and access to credit services were found to be relevant to climate change perceptions.

Prior knowledge of climate change and its impact helps in making anticipatory adaptation decisions that can minimize climate change impact. The role of perception in adaptation decision is well supported and acknowledged by empirical research in the field. Future climate change expectations are particularly relevant as they influence farmers' adaptation strategies and decision-making processes. To motivate farmers for climate change adaptation, policy makers need to ensure that their actions and strategies are in accordance with farmers' clear and accurate perceptions of climate change and the associated potential risk it poses. Therefore, we recommend the provision of locally targeted and stakeholder-specific extension and advisory services to enrich climate change understanding and to guide appropriate farm-level climate change adaptations. Based on our findings, this is especially pertinent in considering local conditions and demographic characteristics such as farmers' education level, gender, and age. The result also signifies the need for information provision to farmers who have fertile soil and less access to credit services.

To summarize, we emphasize the need for information provision and upgrading of basic education levels in the study area, particularly focusing on those farmers who are illiterate and lack adequate access to climate change information. Provision of climate change-related information through various outlets may be useful to distribute timely and relevant information to farmers. Institutional measures and arrangements such as improving agricultural extension services can have increased impact in facilitating information exchange and motivating farmers to take action.

Acknowledgments The first author has received a scholarship from Katholischer Akademischer Ausländer-Dienst (KAAD) and the Laura Bassi award from Technische Universität München for PhD study. This study is part of the PhD work. The authors would like to thank the three anonymous reviewers for their constructive comments, which helped us to improve the manuscript. We would like to thank Habtamu Y. Ayenew for very valuable discussions and suggestions on the analysis.

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Publication III Manuscript

Habtemariam LT, Abate Kassa G, Gandorfer M and Heissenhuber A.Climate Change Adaptation in Smallholder Agriculture: A review. *Agricultural Economics Review*, Submitted

Climate Change Adaptation in Smallholder Agriculture: A Review

Abstract

Adaptation is one of the main strategies to reduce the risks of climate change on agriculture. Being the most vulnerable agricultural system, the practical relevance of climate change adaptation is particularly significant for smallholder agriculture. As a result, it has become an important research area in the climate change field. A growing research is contributing in different contexts including studies that investigate ongoing farm level adaptations, evaluate adaptation options under future climate change, and studies that estimate the costs of adaptation. Work from socio-economic studies that investigate farmers' adaptation decisions, biophysical studies that assess the potential of adaptation strategies in terms of increasing productivity and studies that assess the economic costs of adaptation have majorly contributed to the literature. This paper provides an overview of the key issues, methodological approaches and the main findings reviewing the climate change adaptation literature that focuses on smallholder agriculture. Among the key issues in the adaptation literature are the conceptual and methodological complexity and specificities of smallholder agriculture system required to model the adaptation decision-making process of farmers and to assess the impacts of adaptation. Other issues in the literature include the uncertainties related to climate and socio-economic trends in the future, and the need to recognize the role of cognitive and psychology theories in explaining adaptation behaviors. As the effectiveness of adaptation actions depends on the specific biophysical, socio-economic, and policy opportunities and constraints that a specific location entails, there is the question of the lack of generality and transferability of adaptation to other contexts. Furthermore, thematically the literature shows a gap in terms covering adaptation in the

livestock sector, the role of off-farm policy adaptation, assessing transformative adaptation types, and the temporal aspect of adaptation.

Key words: Adaptation, Determinants, Evaluation, Cost-estimation, Mainstreaming

1. Introduction

Agriculture remains a major economic activity for many developing countries, and the primary source of livelihood for the vast majority of the rural population in these countries (Rapsomanikis 2015). The average share of agriculture in GDP for example for Sub-Saharan Africa, is more than 10%, for some countries the share reaching up to 40% or more; which is far bigger than the global average (Tomsik et al. 2015). The agriculture in developing countries is dominated by smallholder farms that have average landholding of less than 2 ha (Rapsomanikis 2015) and it is characterized by low productivity that arise due to lack of access to technology, credit, market as well as environmental constraints (Salami et al. 2010). Environmental conditions such as declining soil quality, inadequate irrigation access, dry climate and highly variable rainfall constrain agriculture production in many Sub-Saharan Africa and South-Asia countries (Rapsomanikis 2015; Reynolds et al. 2015).

As the globe continuous to warm, the climate change brings many additional challenges to these farms, exacerbating existing farming constraints. Changes in temperature, rainfall and the frequent occurrence of extreme weather events all pose major challenges to agriculture hindering the achievement of food security (Anwar et al. 2013). Crops become less productive in temperatures above the physiological maxim, changes in rainfall amount and timing affects crop calendars and hence productivity and marginal lands may become unsuitable for agriculture due to climate change. The risk of climate change has been particularly critical on smallholder agriculture for two main reasons i.e., due to their tropical location and their level of development.

Most of the smallholder farms are geographically located in warm regions, which make them sensitive to even marginal changes in temperature i.e., small changes in the climate may result in significant reduction in agricultural productivity and hence affecting their agricultural based livelihood. Also, the smallholder-farming systems do not have the technological, resource and institutional capacities to respond to the adverse effects of climate change, and hence are the most vulnerable to climate change (Morton 2007). As the international effort to combat climate change through mitigation actions lacks significant progress, these farms will continue to be affected and face even greater climate change risks under future climate.

As the risks of climate change became apparent, there has been an increasing research focus to understand the impact of climate change and adaptation in smallholders' agriculture. Most of the early studies of climate change had focused on impact and mitigation research, whereas adaptation emerged as an important subject of research and policy discourse later (Mertz et al. 2009), when adaptation become increasingly regarded as one of the main strategies to deal with the climate change (Burton et al. 2011). The climate change adaptation literature is dominantly informed by socio-economic (Deressa et al. 2009; Gbetibouo 2009; Jain et al. 2015), biophysical (e.g., Kassie et al. 2015; Babel et al. 2011; Singh et al. 2014), adaptation cost (World Bank 2010a; UNFCCC 2007), and policy and development related studies (Ayers et al. 2014). The socio-economic research aimed at informing adaptation policy and the design of strategies that facilitate uptake of adaptation actions by studying variables with most significant association to farm level adaptation decisions (e.d., Burton et al. 2011; García de Jalón et al. 2016). The studies from biophysical research field have mainly focused on identifying and evaluating the potential of adaptation measures to reduce the impact of climate change on crop productivity (e.g., Babel et al. 2011; Singh et al. 2014; Kassie et al. 2015) and cropping systems (e.g., Waha et al. 2013).

The adaptation cost research has sought to estimate and understand the magnitude of economic costs to finance adaptation (e.g., World Bank 2010). The main elements of the climate change adaptation and development research has been about the processes and options to integrate climate change adaptation into development policies and to reduce the factors that cause vulnerability (Ayers et al. 2014).

Although the available literature provided some important insights to understand the climate adaptation processes, benefits and costs, many issues that hold significant implication for effective adaptation under diverse climate, environmental and socio-economic contexts remain inadequately addressed. Climate change adaptation is location-specific where its effectiveness depends on the specific biophysical, socio-economic, and policy opportunities and constraints that specific location entails. Given the heterogeneous characteristics of smallholder agriculture in terms of the range of climate regimes and other environmental differences, the wide range farming systems and socio-economic factors; there is lack of generality of effective adaptation strategy. Hence, there is a particular need to address explicitly all these pertinent aspects in smallholder climate change adaptation research. Morton (2007) shows at length the conceptual and methodological complexity and specificities of smallholder agriculture and the implications in climate change research. The uncertainties related to climate and socio-economic trends in the future (Refsgaard et al. 2013) is by itself a unique challenge in climate change research and thus an additional aspect in climate change and adaptation studies. It is required to sufficiently understand and address all these specificities and uncertainties in order to effectively adapt agriculture to climate change.

This paper presents an overview of the important research areas and issues, and some of the research needs in association to adaptation studies that focus on smallholder agriculture. The literature review starts by providing highlights into a typology of adaptation established in the available literature. In the next section, more context is provided to discuss the particular importance of adaptation in smallholder agriculture systems. Wide-ranging empirical researches, their conceptual foundations, methodological approaches, and findings are then discussed in detail in section four. Issues that need further research are discussed in the last section .

2. Types of climate change adaptation

Regardless of current and future mitigation actions, adaptation is an indispensable response action to cope with the inevitable climate change; climate change that will occur due to past emissions (Bedsworth and Hanak 2010). It involves the adjustment of actions, practices, or processes of natural and human systems in response to observed or expected changes in climate (IPCC 2007c). Adaptation minimizes climate change impact either by reducing *vulnerability* to climate change or by increasing *resiliency* (Bedsworth and Hanak 2010). One of the important components of adaptation discussion is the timing of adaptation action. For example, adaptation can be taken as a *reactive* measure, in which case actions are undertaken after experiencing an initial impact, or as an *anticipatory* measure, in which case measures are undertaken ahead of time before experiencing any impact (Smit et al. 2000). In this respect, a reactive adaptation measure has a drawback for allowing climate change to have an initial damaging effect, whereas anticipatory adaptation strategy is hindered by "*the uncertainties surrounding the pace, pattern, extent and severity of climate change*" (Ikeme 2003, pp 32).

In terms of actors and scale, adapting agriculture to climate change can involve multiple actors, can take place at different scales and can involve multi-dimensional changes (Maskey et al. 2016; Bryant et al. 2000). The literature has made a distinction between *planned* and *autonomous* adaptations. Planned adaptation refers to an adaptation measure, which is a result of a deliberate policy decisions and actions based on prior knowledge of anticipated changes; whereas autonomous adaptation refers to an independent responsive action or adjustment undertaken by an individual, an institution, or a group and one that does not require higher-level policy changes (Smit et al. 2000). In terms of forms of adaptation, a wide range of adaptation measures which take *technological, economical and institutional* forms (Smit et al. 2000) can be applied to reduce the negative impacts of climate change. For example, a number of adaptation mechanisms have been suggested in agriculture ranging from changing agricultural technologies and practices to diversification of income from non-farm section, and financial risk management strategy through insurance (Anwar et al. 2013). It is suggested that a combination of autonomous responses actions, accompanied by policy and institutional changes that create enabling conditions should constitute adaptation strategies for rural agricultural communities (Soussan and Burton 2002).

3. The role of adaptation in smallholders agriculture

Smallholder agriculture is expected to respond simultaneously to the risks of climate through adaptation and at the same time expected to improve productivity to ensure food security for the many rural populations. Furthermore, the potential contribution of smallholder agriculture to climate change mitigation has been a topic emphasized and discussed in recent climate change researches. That is, farming practices in smallholder agriculture are increasingly being evaluated in terms of their potential to increase productivity, resilience to climate change effect and their potential to mitigate climate change. The concept of climate smart agriculture is one of the concepts being adopted in this regard. A number of farm level climate change adaptation measures have been suggested to potentially reduce the impact of climate change including the adoption of new crop varieties, changing farming practices, adjusting planting timing, wider use of input and technology, crop diversification, and income diversification (Howden et al. 2007; Smit and Skinner 2002). In this regard, many of the suggested climate change adaptation measures in the literature are expected to provide benefits to increase productivity beyond increasing the resilience to climate change impact though with some trade-offs in some cases (Bryan et al. 2011). Adaptation practices in agriculture are also justified as more than merely actions of responding to climate change but rather actions that go well hand in hand with the principles of established sustainable agricultural practices (Wall and Smit 2005).

Furthermore, adaptation in general is considered as an opportunity to assess the problems of environment and development from a new perspective (Schipper 2007b). Adaptation may provide development benefits (Ikeme 2003) or it may help as a complimentary policy option for development. The climate change adaptation preparedness and capacity of many developing countries is, however, in question (Ikeme 2003). Adaptation requires financial and technological resources, institutional capacity, and many developing countries currently lack this. Adaptation efforts, therefore, face many challenges and further research may provide opportunities to climate change adaptation in smallholder farming.

4. Adaptation research in smallholder agriculture

4.1 Current farm level adaptation

Farm level adaptation is considered to be a key component of adapting agriculture to climate change (Howden et al. 2007) and many climate change adaptation studies of smallholder agriculture have focused on farm level adaptations taking the farmer as an adaptation decision-maker. These studies have characterized and assessed current farmers' on-farm adaptation strategies in response to observed climate change in an attempt to identify the determinants to taking adaptation actions (Deressa et al. 2009; Gbetibouo 2009; Bryan et al. 2013; Esham and Garforth 2013). Economic concepts and econometric models of household decision-making are applied to highlight the relationship between the decision to adapt and various household and farm characteristics, as well as economic, biophysical, and institutional factors. These studies have indicated that farmers are currently adapting to climate change to a certain extent and provided relevant information on target variables for the development of policies and strategies that aim to enhance farm-level adaptations.

One of the methodological issues regarding to modelling farm-level adaptation is that often farmers implement a combination of adaptation strategies, and thus modelling needs to account for common factors and relationships between the different adaptation strategies (Charles et al. 2014). Some studies have used multivariate discrete choice econometric model instead of multinomial choice model to avoid the large number of possible combination of adaptation strategies that need to be modelled (e.g., Charles et al. 2014) while others have chosen to use multinomial modeling just for selected adaptation strategies (e.g., Deressa et al. 2009).

A range of studies across different countries reveal that the physical environment, social, economic, institutional, and cultural characteristics of production systems are important in conceptualizing the adaptation decision-making process of farmers. This suggests that , since the existing local particularities (either constraints or opportunities) affect farm level adaptation choices and decisions, the transferability of research findings to other contexts is limited (Elbehri and Burfisher 2015).

Furthermore, in a similar line of research, recent scholarly works are suggesting psychological and cognitive factors that did not get much attention in earlier studies to influence smallholder farmers' adaptation decision-making (Esham and Garforth 2013). This recent approach stems from theories in psychology and behavioral economics (Grothmann and Patt 2005) that relate risk perception to response action. These studies have added to the climate change adaptation literature by providing evidence on the need to go beyond resource, socio-economic and institutional constraints and consider cognitive factors in the development of adaptation strategies.

Other studies on on-farm adaptation have assessed the farm productivity implication of adaptation (e.g., Di Falco et al. 2011; Yesuf et al. 2008). In these studies, the benefits of on-farm adaptation strategies in increasing food productivity are estimated by building an actual and counter factual analysis and comparing farm households that adapted and those who did not (Di Falco et al. 2011). Insights from these studies have been relevant in providing evidence on the extent to which adaptation can increase productivity and secure food availability within the current climate conditions. The focus on productivity instead of economic return and land value (as it was done in many Ricardian analysis of climate change impact) has been an important approach and particularly feasible to developing countries context where land markets are not working properly (Di Falco et al. 2011). Regarding to estimating the effect of adaptation in productivity, endogeneity is one of the methodological issues. Because the decision to adapt is self-determined and there is a possibility that farmers who adapted are systematically different from farmers who did not adapt (Di Falco et al. 2011). That is, without controlling for potential endogeneity it cannot be sure if the difference in productivity is in fact due to adaptation, and this may lead to the wrong conclusion about the benefits of adaptation.

One of the important issue in assessing farm-level adaptation has been the complexity of drivers of farming practice changes (Mertz et al. 2009b), which makes it difficult to isolate which adaptations are actually in response to climate change. Because, besides adapting to climate change, smallholder farmers have been simultaneously adapting to non-climate drivers and stressors in an attempt to respond to low-productivity, declining soil quality, market demands, introduction of new technologies, local development policies and so forth (Wood et al. 2014).

The non-climate driven response actions can have beneficial effect or may ‘incidentally’ serve as an adaptation to climate change (Smith et al. 2000), but in the long run they may also generate unintended consequence (Adger et al. 2005). The lack to distinguish climate change targeted farm level adaptation from non-climate driven economic maximizing strategies in farmers’ adaptation assessment may lead to a misconception of climate adaptation decision and processes.

Agricultural household surveys that include questions specifically addressing the climate and non-climate driven elements of farm adaptation can be instrumental to address this concern. For example, increased use of fertilizer and chemicals might be mainly due to diminishing soil fertility status and higher incidence of pests and diseases. Changes on livestock activity could be linked to economic reasons; and the use of improved seed and changing crop type might be linked to low yield productivity of old varieties and some crop types. In this regard, some commonalities between climate and non-climate driven adaptation are expected, nonetheless a systematic difference in climate change targeted and non-climate driven farming modifications is possible. It would be appropriate to know if the most commonly applied climate driven modifications made by farmers are activities that entail less or more economic investment as compared to the non-climate driven modification. Besides, it is important to know whether farmers are applying diversified climate change adaptation measures, and whether farmers’ actions are rather not non-climate driven strategies. That is, without detailed investigation it is hard to tell the motive behind farming modification as response actions often overlaps.

4.2 Assessment of potential future adaptation measures

Assessing the potential of adaptation options in alleviating climate change impact has been important to identify strategies required for agriculture under future climate as well as to weigh the cost-benefit of mitigation actions (Lobell 2014). A set of climate adaptation research that has assessed the potential of adaptation options on smallholder agriculture has contributed in this regard. In this effort, researchers have predominantly used biophysical simulation approaches to evaluate the benefits of technological adoptions (e.g., improved crop varieties) and agronomic adjustments (e.g., planting date adjustments) to improve yield of a certain crop in the face of climate change. Adaptation options have been assessed for maize (e.g., Waongo et al. 2015; Wang et al. 2012; Tao and Zhang 2010; Choudhary et al. 2015; Byjesh et al. 2010), wheat (e.g., Challinor et al. 2010; Wang et al. 2012), rice (e.g., Shrestha et al. 2016; Saxena and Kumar 2014; Bhuvaneswari et al. 2014) and potato (e.g., Kumar et al. 2015). The studies have provided quantitative information that can help policy makers to set priority for adaptation-technology investments and information that can be used by farmers on farming adjustment decisions. However, the literature has also highlighted how adaptation options can be varied depending on the specific local agro-ecology, crop characteristic and the spatio-temporal variation in projected future climate. For example, the study by Waongo et al. (2015) suggests that the potential of planting date adjustment as an adaptation option to increase maize yield varies over location within a country; limiting the spatial dimension of the applicability of adaptation.

Although biophysical modelling of adaptation options has been proven to be very useful in adaptation research field, concerns have been expressed by Lobell (2014) on issues related to logic, as well as model and management assumptions made in modeling. Lobell (2014) argues that studies might have exaggerated adaptation benefits due to wrong logics made about reference scenario of adaptation options, limitations of crop models in their ability to simulate some processes such as moisture stress and researchers failure to account for future management changes. Nevertheless, inclusion of adaptation option assessment in biophysical modelling has been crucial to overcome the limitations of biophysical impact assessment studies that simply assess climate impact without consideration of adaptation, which are believed to exaggerate the impact of climate change (Mendelsohn et al. 1994).

Another issue with regard to assessing the potential of adaptation is that other than modelling the change in productivity with respect to a hypothetical adaptation strategy from a purely biophysical point, often studies do not model farmers behaviors and the dynamics of adaptation under future climate and socio-economic conditions (Dolan et al. 2001). Therefore, we lack to have a complete understanding of the potential success of adaptation strategies in future conditions. Also, the economic efficiency of farm adaptation strategies are often not assessed, and whether the economic benefit would outweighs the cost is relevant to know (Dolan et al. 2001). If productivity increase from adopting a new technology or changing farming trend comes with a higher cost, its acceptance level would be very low from an economic perspective of farmers.

4.3 Economic costs of adaptation

Understanding the costs of adaptation have been paramount for many reasons including for country-level adaptation strategy design, for climate change funding negotiations, for international support of adaptation in developing countries (Parry et al. 2009) and for farm level adaptation decisions. The available literature on costs of adaptation in developing countries agriculture have included country-level assessment, for example, the World Bank (2010) case study on seven countries - Bangladesh, Bolivia, Ethiopia, Ghana, Mozambique, Samoa, Vietnam, that provides country level costs of adaptation including sectoral-level cost break-down. Other studies have aggregated result for developing countries (UNFCCC 2007; World Bank 2010) and some others have made global level assessments with sectoral detail (World Bank 2010; McCarl 2007). Country level NAPAs (National Adaptation Program of Action – prepared by least developed countries to identify priority adaptation activities and needs) - also provide information on costs of priority adaptation projects for the respective activities they propose that included projects in the agriculture sector (Agrawala et al. 2008).

Estimating adaptation costs often consists of comparing a future world without climate change against a future world with climate change, and estimating the costs needed for additional actions to live in the new world with climate change (World Bank 2010). This involves development of a baseline period, future climate projection, predicting impacts, identifying adaptation options that can be pursued and costing of adaptation options (World Bank 2010). Some adaptation studies have assessed the economic cost of adaptation by assessing the investment needed for *productivity-enhancing* investment in agriculture (Nelson et al. 2009). For example, Nelson et al. (2009) identify agricultural productivity investments that reduce child malnutrition and compare with-climate-change to no-climate-change scenarios. The existing literature have provided a wide range of adaptation cost estimates which have been subjected to the methodological approach applied and the climate change scenario considered, among others (Parry et al. 2009). For instance, estimates of adaptation costs suggest about $3.3 billion annually between 2010 and 2050 for investment in agriculture for Sub-Saharan Africa to maintain nutrition levels for children (World Bank 2010) and a similar study by Nelson et al. (2009) estimates about $ 2.9- $3 billion annual investment. Estimating adaptation costs is complex and previous studies have recognized many methodological challenges (Parry et al. 2009). Some of the crucial points included issues on "*adaptation objectives, baselines, discounting, equity, transferability and additionality*" as discussed in detail by Watkiss (2015, pp. 20). Overall, the literature on quantification of adaptation costs is dominated by gray literature and the published scientific contribution is considered to be infant but growing (Bosello et al. 2011).

4.4 Mainstreaming adaptation in policy and development

Another main issue in the adaptation literature is regarding integrating adaptation into existing development planning and poverty reduction strategies. Because of the close link between climate change adaptation and regular development activities, some studies have focused on the topics of *mainstreaming* adaptation into development plans and sectoral decision making (Ayers et al. 2014; Adger et al. 2003). It is clear that reducing climate change vulnerability cannot be achieved only by mitigation and adaptation actions but improving the living conditions and capacities of farmers is equally important (Klein et al. 2007). Also, many adaptation activities have the capacity to benefit the wider and existing sustainable development objectives (Yamin 2005). Addressing the underlying causes of climate change vulnerability (Schipper 2007) and mainstreaming climate change adaptation into national development policies can be thus a central part of successful adaptation process and it allows more efficient and effective use of resources (Ayers et al. 2014). Nonetheless, despite being promoted by many international funding agencies (Cuevas et al. 2016) the notion of mainstreaming has been debated by some researchers from its lack of sound theoretical foundation that can enable to evaluate success and challenges of mainstreaming (Persson and Klein 2008) and in association to donors financial funding of regular development projects vs adaptation activities (Yamin 2005).

Despite this, scientific publications have contributed in terms of providing frameworks and guidelines about mainstreaming adaptation into agricultural and other sectors policies and programs (FAO 2012; Ayers et al. 2014). Other studies discuss lessons learned in practice drawing on experiences of various countries to show to what extent adaptation can be integrated into development plan in agriculture and other sectors (Huq et al. 2004; Rhodes et al. 2014). For example, Ayres et al. (2014) show the potential strategies to mainstream climate change adaptation in various sectors including how to incorporate climate change considerations into agricultural projects in Bangladesh. And some other researchers made agricultural policy assessment studies of countries specific national policies and strategies to identify gaps in mainstreaming (Liwenga et al. 2014). Assessment of current agricultural policy in the context of development is important because this will affect, for example, crop choices for export purpose which may relate with adaptation (Burton et al. 2011). It is suggested that many developing countries have not yet adequately mainstreamed adaptation into development plans (Liwenga et al. 2014) and studies that have assessed countries agricultural policies and strategies have indicated that there is a need to revise policies.

Scientific research has also contributed into identifying barriers to implementation of mainstreaming (Cuevas et al. 2016). In order to cope with this issue, , researchers have developed a mixed model approach that includes quantitative metrics to measure challenges of mainstreaming and institutional issues in the adaptation of mainstreaming. One other related issue in mainstreaming adaptation is identifying key adaptation needs specific to the region or location. For this, farmer-based analysis of adaptation need might help policy makers to better identify areas that need intervention to enable farmers to adapt to climate change. One may anticipate a spectrum of intervention areas that farmers identify ranging from irrigation infrastructure to creation of job opportunity, to construction of road infrastructure and others. Most of the intervention areas could also be a significant cause of lower agricultural productivity and the determinants of food insecurity and poverty. It is thus worth investigating through scientific research intervention areas identified by farmers and their feasibilities in a spatially explicit manner to provide policy support tailored to local circumstances. It is also important to study the identified intervention areas in a systematic way in terms of their potential for adapting to future climate change as well for their potential to improve the overall livelihood situation of farmers.

4.5 Research needs related to adapting smallholder agriculture to climate change

The adaptation literature that focuses on smallholder agriculture is growing and evidences are emerging that shed light on our understanding of the potentials and costs of adaptation, the process of farm level adaptation decisions, and the link between development planning and poverty reduction strategies. Nonetheless, many issues need further investigation. One of the main issues is the highly location and context -specific nature of adaptation. It means, instead of extrapolating results from one context to another, there is clearly a need to widen the coverage of research to investigate local socio-economic circumstances and wide-ranging agro-ecologies for adaptation. In addition, given that adaptation effectiveness has a temporal dimension, variation in climate change and adaptation needs to be well represented in the literature. In terms of thematic focus much focus has been given on crop production and there is very little information regarding to adaptation in pastoralist contexts (Descheemaeker et al. 2016). Since climate change will affect livestock production as well, there is need to understand what adaptation, and to what extent adaptation can reduce impact in this sector. Moreover, because current marginal or incremental farm adaptations are only limitedly effective under strong climate change (Howden et al. 2007), we also need to focus and research on transformational adaptations too (Anwar et al. 2013). Transformative adaptation such as the development of new technologies and new institutional arrangements are expected to be essential in the long-term especially when the change in climate becomes stronger (Kates et al. 2012).

Another point is, research has provided insight into understanding the role of farm-level adaptation but other potential off-farm policy adaptations that go beyond the farm such as market interventions and changing land tenure systems are not well investigated (Burton et al. 2011). It is not yet sufficiently studied about the implications of climate change adaptation on food and nutrition security. Also, research needs to be strengthened with respect to assessing the feasibility of insurance strategy as a means to assist adaptation to climate change and the associated decision of farmers whether to enter or not in an insurance scheme to adapt to climate change. Furthermore, the practical application of studies that develop adaptation strategy based on ' analogue locations' through the analysis of environmental and socio-economic criteria's of locations are promising and such efforts should be increased in the future (Leal Filho and Mannke 2011).

Regarding to methodological challenges, research that focuses on the agriculture of developing countries often face data limitations. Devising methods that are robust but one that requires minimum data would be essential to ensure effective use of available data. In terms of conceptualizing farmers' adaptation decisions, it would be very crucial to go beyond socio-economic and institutional factors and conceptualize the adaptation decision process of farmers by taking risk perception and experience as an important component of adaptation decision process. Empirical evidence on the role of risk perception variables influencing farmers' adaptation decisions will have high relevance in shaping policy strategies that aim to enhance farm level adaptation.

5. Conclusion

Adaptation is a necessary strategy in smallholder agriculture to minimize the impacts of climate change. The scientific literature is increasingly contributing in terms of providing evidence to understand current farm adaptations, the role of adaptation in agriculture, the costs of adaptation, and the scope to mainstream adaptation into existing policy and development strategies. Diverse conceptual and methodological approaches have been used in the literature to investigate farmers' adaptation decisions, to assess the potential of adaptation strategies in terms of increasing productivity and to assess the economic costs of adaptation. However, there are still research gaps which needs further investigation in terms of thematic, spatial and temporal coverage, and in terms of conceptual and methodological approach. For example, adaptation in the pastoralist sector is not well investigated despite climate change threatening the livestock sector too. There is also a need to cover diverse agro-climatic and socio-economic contexts, as adaptation is highly peculiar to local specificities. As it is now, focus has been given to adaptation in the near term with less emphasis on transformative adaptations, which are needed under strong climate change in the long term. The conceptual approaches that have been applied to study farm level adaptation decisions needs to be expanded to include the role of risk perception and experience variables. Policies that seek to minimize the impacts of climate change on agriculture through adaptation need to consider the potential adaptation alternatives, the capacity to be adopted by the wider farm population and the costs of adaptation.

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Publication IV Manuscript

Habtemariam LT, Gandorfer M and Abate Kassa G. Risk experience and smallholder farmers' climate change adaptation decision. *Climate and Development*. Submitted

Risk Experience and Smallholder Farmers' Climate Change Adaptation Decision

Lemlem Teklegiorgis Habtemariam[a], Markus Gandorfer[b] and Getachew Abate Kassa[a]

[a]Chair of Agricultural Production and Resource Economics, Technische Universität München, Alte Akademie 16, 85350, Freising, Germany

[b]Chair of Economics of Horticulture and Landscaping, Technische Universität München, Alte Akademie 14, 85350, Freising, Germany

Abstract

Farm level adaptation can offset some of the negative impacts of climate change and can reduce the risk of household food insecurity. Understanding farmers' climate change adaptation decisions is vital to promote farm level adaptation policy interventions. Literature shows that different socio-economic, institutional as well as risk experience variables may relate to climate change adaptation and mitigation decisions. However, research on the role of risk experience on climate change adaptation and mitigation decisions is limited and previous findings are inconclusive. The present study assesses whether perceived risk experience in terms of agricultural production shocks and yield reduction influence farmers' decisions to adapt. Data collected from smallholder farmers in Ethiopia has been used for this purpose. The study applies a multivariate endogenous probit model and controls for potential endogeneity of perceived risk experiences to adaptation decision. The results indicate that farmers who have the perception of experiencing production shocks are more likely to decide to adapt. Experience on yield reduction is not found to be associated with adaptation decision. Socio-economic, institutional and agro-ecological variables including gender, education, household size, and participation in agricultural services are also found to be associated with adaptation decisions. These findings suggest that it is essential to build farmers adaptation capacity in terms of resource and information as well as increase climate change risk perceptions through risk communication. Risk communication

strategies that provide clear messages on the future risks of climate change may have the potential to motivate farmers for adaptation and to increase household food security.

Keywords: Risk experience; Adaptation; Yield reduction; Production shock; Food security

1. Introduction

Climate change poses a major risk to agriculture (Rosenzweig et al. 2014) threatening food security in some resource-dependent regions (Wheeler and Braun 2013). Food production, which is the main determinant of food availability and hence food security, is anticipated to decline in these regions (Schlenker and Lobell 2010) and other dimensions of food security will be affected as well due to climate change (Schmidhuber and Tubiello 2007). Adaptation has become one of the main strategies in dealing with the risks of climate change (Howden et al. 2007; Smit et al. 2000), particularly relevant in developing countries' farming systems. Adaptation involves any action or "adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities" (IPCC 2007). The literature suggest that adaptation provides substantial benefits to offset negative climate change impacts and to reduce associated risks in agriculture (Di Falco et al. 2011; Howden et al. 2007; Mainuddin et al. 2011) that can minimize the risks of food insecurity. However, field surveys show that smallholder farmers are adapting to climate change only to a certain extent with a considerable number of farmers implementing limited or no climate change adaptation. For example the studies conducted by Deressa et al. (2009) in Ethiopia, and Maddison (2007) that assessed farmers from ten African countries, report many cases in which almost a third or more of the sampled farmers have implemented no adaptation.

Despite locally observed rainfall and temperature changes (Habtemariam et al. 2016), and the potential positive effects of adaptation, why some farmers are not adapting to climate change has been a subject of research interest. Previous adaptation studies have identified a range of socio-economic, biophysical and institutional determinants of farmers climate change adaptation decisions (e.g., Charles et al. 2014; Deressa et al. 2011; Hisali et al. 2011; Jain et al. 2015; Mehar et al. 2016). These studies found a link between farmers' adaptation decisions and factors such as gender, education, age, household size and financial accesses. These factors and farmers' adaptation decisions have been linked in terms of determining access to resource and information required for adaptation.

Some evidence suggests that risk experience variables may also relate to climate change adaptation and mitigation behaviors (Grothmann and Patt 2005; Spence et al. 2011), and influence climate change adaptation and mitigation decisions by affecting risk perception (Weber 2006). Climate change risk experience reduces the uncertainty associated with the occurrence and severity of climate change risk and maximizes risk perception (Grothmann and Patt 2005). Higher risk perception is assumed to motivate for a response action. However, there have been limited studies that empirically assessed the role of risk experience and perception in the climate change adaptation decision of smallholder farmers.

Given the probability of further changes in the global climate system (IPCC 2013), farm level adaptation is essential to reduce the additional negative impacts on agriculture. Policy interventions that aim to reduce the risk of food insecurity through enhanced farm adaptation to climate change need to better understand the factors that determine farmers' adaptation decisions. In addition, risk perception and related variables have high implications for policies that attempt to change behavior by fear appeal (Neuwirth et al. 2000; Rogers 1983). In a similar way persuasive risk communication strategy can also be used to influence climate change adaptation decisions, for example, by providing persuasive information on climate change risk in a way that create concern and demonstrating potential measures that can be applied.

This study contributes to the climate change adaptation literature by providing empirical evidence on the role of risk experience related variables in smallholder farmers' climate change adaptation context. Using household survey data that included information on questions that capture this aspect of adaptation and related risk factors, the study attempts to answer the following questions: 1. What are the main climate change adaptation measures farmers plan to implement in the future? 2. Does perceived risk experience in terms of crop yield reduction and production shock influence farmers' climate change adaptation decisions? We provide empirical evidence on this issue by addressing concerns regarding the potential endogenous nature of perceived risk experience to adaptation decision. The result of this study is expected to address important policy questions that intend to alter farmers' adaptation behavior and facilitate further climate change adaptation to improve food security.

In the remaining part of this paper, section 2 describes the relation between risk experience and climate change adaptation decisions and the implication for food security. Section 3 explains the materials and methods used in the study, section 4 describes and discusses the result. Finally, the conclusion and policy implication part is presented in section 5.

2. Risk experience and perception as an influence on adaptation decision

Agricultural productivity reduction is a major risk that smallholder farmers face as a result of climate change (Schlenker and Lobell 2010). In the past, many smallholder farmers in different parts of the world have observed a decline in crop productivity attributed to climate change (Habtemariam et al. 2016; Hussain et al. 2016). The challenges that climate change pose on smallholder farms have been particularly widely articulated, as smallholder agriculture remains to have a significant contribution to both farm and non-farm based households' food security in developing countries. In some cases it has been found that the contribution of agriculture to household food security has significantly decreased as farms are becoming increasingly vulnerable to climate change (Hussain et al. 2016; Shrestha and Nepal 2016). A number of farm level climate change adaptation measures have been suggested to potentially reduce the impact of climate change including adoption of new crop varieties, changing farming practices, adjusting planting timing, wider use of input and technology, crop diversification, and income diversification (Howden et al. 2007; Smit and Skinner 2002). Changing farming practices in response to observed changes such as climate relates to food security status of farms; though the direction of causality between the two can potentially go in both directions (Kristjanson et al. 2012). In terms of benefit, the role of climate change adaptation in increasing food productivity is expected to be higher for farms, which are currently not adapting (Di Falco et al. 2011), suggesting the importance of promoting adaptation particularly among farms that have not yet adapted.

The implementation of adaptation measures entails some financial investment, requires access to technologies as well as skill and knowledge aspects. The lack of uptake of adaptation measures by smallholder farmers has been also mainly linked to resource and information constraints. Given the typical characteristics of smallholder farmers' production system, it is expected that their adaptation can likely be influenced by the limited resources endowments and limited access to information. Limited access to resources such as improved seed, input and irrigation water reduces farmers' adaptation capacity and can hinder them from implementing adaptation measures. Lack of awareness about potential adaptation options can impede farmers from undertaking adaptation.

However, besides resources and information, risk perception has been implicated to simultaneously play a role in individual adaptation and mitigation decisions in climate change and related risks (Gifford 2011; Grothmann and Patt 2005; Truelove et al. 2015). Driving from the protection motivation theory (Rogers 1983), Grothmann and Patt (2005) conceptualize perceived risk appraisal as an important component of individual adaptation decision process. Individuals are assumed to start contemplating about response action after perceiving a risk from climate change on their livelihood (Grothmann and Patt 2005). Thus, the process whereby an individual decides whether to take adaptation or mitigation measures may relate to her/his climate change risk perception, which can intern be influenced by the personal risk experiences. Personal risk experience may play an essential role in maximizing risk perception (Grothmann and Patt 2005b; Spence et al. 2011; van der Linden 2014) by reducing uncertainty associated with the occurrence and severity of a risk (Grothmann and Patt 2005). Weber (2006) shows that experience based risk perceptions have importance on decisions to take a response measure against a perceived risk. The risk experience and perception approach to climate change adaptation recognizes that perception on the probability and severity of climate change risk occurrence is an important determinant to motivate individuals for response measure. Therefore, it is assumed that personal experience of climate change and related impacts lead to higher risk perception potentially increasing the probability of response actions.

Previous empirical findings on the influence of risk perception and risk experience on individuals' climate change adaptation and mitigation decision is inconclusive. For example while Spence et al. (2011) found individuals who had direct flood experience to show higher mitigation behavior, Whitmarsh (2008) shows that flood victims differ very little from others in their climate change response, and Tucker et al. (2010) show coffee farmers who perceived extreme weather to be slightly less likely to make adaptive changes. Whitmarsh (2008) suggests that uncertainty to link flooding with climate change as one of the potential reasons for inactions against climate change by the flood victims. On the other hand, Tucker et al. (2010) suggests that constraints such as access to land to be more relevant factors for farmers' adaptation decision than risk perception in their study. The investment risk associated with adaptation, for example, if farmers change coffee land to an alternative crop, may have an essential role in farmers' adaptation decision, particularly if land is a constraint (Tucker et al. 2010).

In the current study, we assess whether perceived experience of yield reduction and production shock influence farmers' adaptation decision within a smallholder farm context. Yield reduction and production shock (production shock refers to shocks such as flooding, drought, frost, and disease and pest outbreaks) are the two main risk elements agricultural producers face due to climate change. Particularly in areas characterized by high level of food insecurity, production shocks and related yield reductions have major implications. Personal experience of the negative outcomes of a risk influences individuals risk perception (Lujala et al. 2015; Weber 2006). In this regard, for example, experience with extreme weather events such as flood, drought, heatwave and the associated damages have been found important to influence risk perception (Dai et al. 2015). In a similar way, an experience of the negative consequences of climate change exemplified in terms of yield reduction and production shock can influence the perception of climate change risk. We hypothesize that farmers who perceive experiencing yield reduction due to climate change or who perceive experiencing production shock in their farms are more likely to make a decision to adapt to climate change. Even though, yield reduction and production shock both represent loss because of climate change, the magnitude of loss associated with the variables is not the same, which may have different implication for risk perception. This argument is consistent with the study finding by Dai et al. (2015) that shows strong relationship between perceived physical or financial damage experience and climate change belief.

The potential benefits of climate change adaptation in terms of improving food production and income is widely acknowledged in the literature. Increased food productivity links to food security both through increased available food for household consumption and through increased income that enables to purchase food from the market. Therefore, economic and farming decisions made by farmers to adapt to climate change and improve productivity have consequences on household farming success and have a major impact on household food and nutrition security. As the threat of climate change becomes more serious and the demand for food increases, enhancing farm level adaptation will be a fundamental intervention step in pursuit of improving rural households' food security. Farm level adaptation can be enhanced by improving enabling conditions such as those associated with financial, informational and , technological capacities and most importantly by understanding the factors that influence adaptation decisions.

3. Materials and methods

3.1 Study area and data description

The study is based on household level survey data collected from smallholder farmers of Ethiopia. Ethiopia is among the countries highly vulnerable to climate change (Thornton et al. 2006). The household data for the current study is from Dugda and Welmera districts located at the semi-arid rift valley area and central Ethiopia, respectively. Long term meteorological records show that the country has experienced climatic changes in the past decades (Tadege 2007a). Rainfall and temperature trends in the study region show a trend of decreasing rainfall and increasing temperature (Habtemariam et al. 2016), a similar trend observed in many parts of the country. The farming system commonly practiced in the study areas is a mixed crop-livestock production system, which is also common in many major agricultural zones of Ethiopia. The major crops grown by farmers are cereals such as wheat, *tef*, barley and maize. Crop production is mainly rain-fed, access to and use of technology and input is low, and the use of mechanized agriculture is rare. Livestock production is also small-scale and mainly for subsistence purposes.

The household data is from face-to-face interviews, which was conducted from November 2012 to February 2013 using a structured questionnaire consisting of both open and close-ended questions. Respondents were farmers randomly selected from six peasant associations (the lowest administrative unit) located in the two districts. Fifty households were selected from each peasant association. Altogether 263 respondents that provided full information on all the variables relevant for this study are included in the analysis. A wide range of questions has been included in the questionnaire addressing issues related to farmers' climate change adaptation plan, climate change impact experience in terms of yield reduction and production shock and related socio-economic information.

3.2 The model of a farmer adaptation decision

A random utility maximization framework has been used in studies that model farmers' behavioral decisions related to adoption of production technologies and climate change adaptation (Deressa et al. 2011; Di Falco et al. 2012; Sheikh et al. 2003). In this framework, the farmer decides to take action if the expected utility gained from taking action (U_A) is greater than the utility gained from not taking action (U_N), that is:

$$U_A > U_N \tag{1}$$

The actual utility level of taking action is not directly observable to the investigator. However, the observed decision of either taking action or no action reveals which one provides higher utility (Greene 2003). The probability of taking action can then be expressed as a function of observed characteristics (X) in the latent variable model as follows:

$$A_i^* = \beta X_i + \varepsilon_i \quad , \quad A_i = \begin{cases} 1 & \text{if } A_i^* > 0 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

where X_i is a vector of explanatory variables that determine farmers decision and ε_i is the error term.

3.3 Empirical model specification

We estimate a binary outcome model of farmers' climate change adaptation decision. The dependent variable is whether a farmer has plan to implement climate change adaptation in the future which takes the value of 1 if the farmer indicated at least one adaptation plan, and 0 otherwise. In the questionnaire, this was documented by asking farmers to indicate what farming practice changes they plan in the future to minimize climate change impact. In contrary to many previous studies we considered farmers' future adaptation plan instead of past adaptation actions for two reasons. First, climate change adaptation measures are not always clearly identifiable (Adger et al. 2005) and farmers can mix direct response measures to climate change with other economic development strategies. Questions that directly refer to planned future measures can minimize this indistinctness. Second, the influence of risk perception is expected to be more reflected on adaptation intentions rather than on the actual adaptation measures. Because other resource related variables may become more important in the realization of adaptation intention into action.

The explanatory variables include variables that represent risk experience and other socio-economic, farm characteristic and institutional factors that may affect farmers' climate change adaptation decisions. This includes gender, age, education, marital status, household size, farm size, farm soil status, agroecology, participation in non-farm income activities, irrigation water access, credit and agricultural extension service participation. Gender, age, education and participation in non-farm income activities and agricultural extension services relate to adaptation (Deressa et al. 2011; Di Falco et al. 2011; Wood et al. 2014a) as they reflect individuals' ability to contemplate about adaptation measures or access to climate change adaptation information that enhances the decision to adapt. Household size, marital status, farm size, farm soil status, agroecology, participation in credit service and access to irrigation water relate to adaptation decision (Charles et al. 2014; Deressa et al. 2011; Di Falco et al. 2011; Wood et al. 2014) as they implicate resource endowments, i.e., labor, financial and natural resource capacity to adapt. Farm size is used here as a proxy for farm income to minimize the number of missed observations in our specific case, as many respondents, being small subsistence farmers, were not able to state their income in the questionnaire. The list of explanatory variables used in the model, their hypothesized effects, and descriptive statistics are given in Table 1.

Risk experience is represented here in terms of farmers' perceived experience of crop yield reduction and production shock. In the questionnaire, respondents were asked to report their experience on yield changes of the five major crops they grow and to indicate their opinion on the reason behind. In the analysis, we represent risk experience using a binary variable to distinguish between respondents who stated experiencing yield reduction because of climate change in at least one crop and those who did not experience any. The questionnaire additionally asked farmers to identify production shocks that have affected their farm. Production shock is represented in the analysis as a binary variable to indicate farmers that have experienced production shock in recent past (it refers to shocks that occurred in the past two years preceding the survey). The focus on recent experiences is because it is believed that more recent negative experiences can have strong influence on risk perception.

In the model, the binary explanatory variables representing perceived risk experience can be potentially endogenous to adaptation decision. Perceived risk is considered to be potentially endogenous because it is a subjective measure that can depend on individuals (Bontemps and Nauges 2015; Whitehead 2006). If similar unobserved factors influence both adaptation decision and the variables on perceived risk experience; parameter estimates obtained by standard probit model can be biased and inefficient. When dealing with endogeneity issue in a binary choice model with more than one dummy endogenous regressor, the application of multivariate probit analysis with recursive structure allows for potential endogeneity of the explanatory variables. A study by Bhattacharya et al. (2006) shows the performance of multivariate probit model in binary dependent variables models with endogenous regressors. The study performs a Monte Carlo exercise to compare the performance of the two-step probit estimator, the two-stage least squares linear probability model estimator, and the multivariate probit; and the result suggest the use of multivariate probit model. A study by Zhang et al. (2009) uses this approach to allow four explanatory variables to be determined endogenously in a binary choice model. Holm and Arendt (2013) discuss other alternative useful estimators such as heckit approximation that can be used to estimate probit models with two dummy endogenous regressors. For our purpose, our main equation of interest is a binary choice model of adaptation/no adaptation; however to control for potential endogeneity issues of the two explanatory variables we estimate multivariate endogenous probit model that allows error term correlations. The multivariate probit model is a class of model to estimate multiple correlated binary choice models jointly. The general specification for K equation multivariate probit model would be:

$$y_{ik}^{*} = \beta_{k}' X_{ik} + \varepsilon_{ik}, \qquad k = 1, \ldots, K \tag{3}$$

$$y_{ik} = 1 \; if \; y_{ik}^{*} > 0 \text{ and 0 otherwise}$$

The error terms ε_{ik} are assumed to be distributed as multivariate normal. The variance-covariance matrix of the error terms has values of 1 on the leading diagonal and the correlation ρ of the off diagonal elements are to be estimated (Cappellari and Jenkins 2003). The correlation ρ indicates whether there is endogeneity problem. If $\rho = 0$, it is assumed that there is no endogeneity problem and standard univariate probit model can yield unbiased estimate.

Our multivariate probit model builds from three binary equations in which one equation represents the structural equation of interest (adaptation decision model) and two reduced form equations for the potentially endogenous dummy variables. Let A_i be the decision whether to implement adaptation measure and, Y_i and S_i be the endogenous binary variables representing the perceived yield reduction and production shock experiences, respectively. The A_i, Y_i and S_i can be modeled as multivariate probit model based on latent variable formulations of A_i^*, Y_i^* and S_i^* as follows:

$$A_i^* = \beta' x_i + \gamma' Y_i + \alpha' S_i + \varepsilon_1 \quad , \qquad A_i = \begin{cases} 1 \; if \; A_i^{\,*} > 0 \\ 0 \; otherwise \end{cases} \tag{4}$$

Where x_i is the vector of exogenous covariates and, Y_i and S_i represents the endogenous explanatory variables 'yield reduction experience' and 'production shock experience', ε_1 is the error term, and β', γ' and α' are the set of unknown parameters corresponding to x_i, Y_i and S_i respectively.

$$Y_i^* = \tau' x_i + \vartheta' S_i + \varepsilon_2 \quad , \quad Y_i = \begin{cases} 1 \; if \; Y_i^* > 0 \\ 0 \; otherwise \end{cases} \tag{5}$$

$$S_i^* = \delta' x_i + \varepsilon_3 \quad , \quad S_i = \begin{cases} 1 \; if \; S_i^* > 0 \\ 0 \; otherwise \end{cases} \tag{6}$$

The stata *mvprobit* program is used to fit the models. The method of estimation is by simulated maximum likelihood methods using the Geweke-Hajivassiliou-Keane (GHK) simulator (Cappellari and Jenkins 2003). The likelihood ratio test of ρ = 0 is used to determine the presence of endogeneity. Though earlier it was thought exclusion restrictions are required in multivariate probit models to avoid model parameter identification problems (Maddala 1983), later it was shown that it is not necessary unless there is too small variation in the data (Wilde 2000). As our model contains three continuously varying exogenous regressors the identification problem can be solved without exclusion restriction.

4. Results and discussion

4.1 Farmers planned adaptation actions

The major climate change adaptation measures planned by farmers are presented in Table 2. While a quarter of the respondents indicated no adaptation plan, some farmers mentioned planning more than one adaptation measure. Most of the adaptation measures refer to alternative activities that aim to generate income, and activities that aim to increase production through improved management. Among the adaptation actions, tree planting and management activities are the most frequently mentioned by 41% of the respondents, followed by irrigation related activities (17%) and soil management and input (13%) activities. The planned adaptation measures are similar to response actions that have been implemented by smallholder farmers in other locations too (Deressa et al. 2009; Hassan and Nhemachena 2008; Maddison 2007; Shisanya and Mafongoya 2016). While tree planting could help farmers as a means of alternative income generation activity, it has also the potential to contribute towards climate change mitigation. These two perspectives may have motivated farmers' higher interest in tree planting. An important issue for local policy makers, however, is to evaluate whether the current trend of planting eucalyptus trees near or at farmlands (which is observed during the survey) will have unintended consequences in the environment. Otherwise it may result to 'maladaptation' (Barnett and O'Neill 2010) that increases vulnerability of crop production to climate change. On the other hand, while irrigation is one important adaptation strategy often cited by the adaptation literature, only 17% of respondents indicated irrigation related activities as future adaptation option. This may be due to lack of access to irrigation water or capital to invest on irrigation equipment. However, very low market prices that are for example associated with localized over-supply of irrigated vegetables are not unusual in some of the study areas. Such market risk experiences may discourage farmers from being involved in the production of perishable vegetables that cannot be stored for next season supply. This suggests that while a certain adaptation strategy may be beneficial by itself, decisions to promote it should be undertaken by considering all other associated factors. It is also important to remember that though a third of the respondents indicated having at least one adaptation plan; the number of farmers who would actually perform the action might be far less due to unforeseen resource constraints during planning.

4.2 Climate change adaptation decision and influencing factors

The result of the multivariate probit analysis is shown in Table 3. The negative correlation coefficients between each of the reduced form equations and the main target equation suggests that the unobservable factors that increase the probability of perceiving risk experience (in terms of yield reduction and production shock) affect the decision to adapt in the opposite way. While the correlation between 'adaptation decision' and 'production shock experience' equations are statistically significant, the correlation between the 'adaptation decision' and 'yield reduction experience' equations are not statistically significant. The likelihood ratio test of $\rho = 0$ between the three equations is significant at the 10% level (Table 3) implying the presence of endogeneity to adaptation decision and suggesting the advantage of parameter estimates using multivariate probit analysis. The result shows that various risk, socio-economic and institutional variables are related with farmers' climate change adaptation decision.

Risk experience in terms of production shock has strong significant positive association with adaptation decision. The positive association implies that farmers who have experienced production shock are more likely to plan climate change adaptation. Perceived experience of crop yield reduction is not found to be associated with adaptation decision. It was expected that farmers that have perceived experiencing yield reduction would be more likely to plan adaptation. The analysis provides no such evidence. A possible reason could be that farmers live in an environment in which crop yield variability prevails not only because of climate change but also due to a variety of other factors related to technological and agronomic causes. Being accustomed to such experiences, it could be that perceiving yield reduction due to climate change did not have strong enough impact to motivate farmers for adaptation. This could be particularly true in the presence of financial and information constraints in which farmers are forced to respond only to extreme cases. The finding on the role of personal risk experience in terms of production shock is similar to empirical findings of Spence et al. (2011) that found individuals who had direct flood experience to show higher mitigation behavior. But inconsistent with Tucker et al. (2010) that found farmers who perceived extreme weather and other risks to be slightly less likely to make adaptive changes. Other studies for instance that studied about agricultural advisors in the US show that experiencing extreme weather events such as drought did not significantly change attitudes towards adaptation (Carlton et al. 2016).

Gender is one of the socio-economic variables found to be a significant factor affecting adaptation decision. The positive coefficient suggests that men are more likely to have adaptation plan than women. Males and females differ in their access to climate change and adaptation information, and resources required to adapt. For instance, males are believed to have better access to both formal and informal source of information in rural societies and are, therefore, better equipped to contemplate about potential adaptation measures. Findings from other authors also show gender to be related with farmers' decision of climate change adaptation (Deressa et al. 2009).

Another important variable is education, which is associated with a higher probability of adaptation plan. Farmers that attended primary and secondary school are more likely to have adaptation plan than those who have not attended formal school. The reason why post-secondary education has not significantly associated with adaptation decision may be due to the few number of respondents (only 1%) that fall in that category. Education increases the cognitive potential of individuals, and access to information on potential response measures (Deressa et al. 2009).

Household size is positively associated with adaptation decision. Smallholders rarely use farm machineries and often use own family labor in many labor-intensive agricultural activities.

Household size is thus labor capital that enables them to perform adaptation and other standard agricultural activities such as tree planting, soil management and irrigation related practices. Therefore, households with higher household size are more likely to plan adaptation action than others. In a similar study, Charles et al. (2014) finds differences between small and large families in terms of practicing more labor-intensive cropping systems in response to climate change. The implication is that providing access to farm machineries that minimize labor requirement may enable small size households to implement adaptation measures.

The agro-ecology where a farmer lives in is associated with adaptation decision. Farmers that live in higher altitude with relatively cooler agro-ecology are found to be more likely to plan adaptation action than those who live in warmer agro-ecology. Initially we expected farmers from the warm agro-ecology to be more likely to adapt because of the higher risks they may face. Agro-ecology represents potential differences in actual risks but it could also represent differences in capacities to adapt in terms of both resource and information.

Participation in agricultural extension service is a significant predictor of adaptation decision. As expected, participation in agricultural extension increases adaptation plan. Agricultural extension service is a main agricultural information channel in rural farming communities. Farmers that participate in agricultural extension services have better information on available agricultural technologies and other promising adaptation measures to climate change. As a result, farmers that participate in extension services are likely to have future adaptation plan than their counterparts. The positive influence of extension service access on climate change adaptation decisions is reported in other studies too (Charles et al. 2014).

5. Conclusion and policy implications

There is evidence that many smallholder farmers are not adequately adapting to climate change. Adaptation is a key strategy to minimize the risk of climate change on food production, meet the increasing demand for food and reduce the threat to food security. As a result, a number of national and international policies and strategies aim to enhance farmers' climate change adaptation and reduce the risks of food insecurity. For this, it is imperative to understand what factors influence the climate change adaptation decision of farmers. Risk perceptions as well as a number of other socio-economic and institutional variables may influence adaptation and mitigation decisions. The current study focused on understanding the role of risk experience on smallholder farmers' climate change adaptation decision. We find some evidence that supports the hypothesis that risk experience motivates farmers for adaptation. However, in our study not all risk experiences lead to adaptation decision. While experience on production shock, which assumed to have bigger magnitude impact influenced farmers' adaptation decision, experience on yield reduction has not showed such influence.

The findings implicate the potential of policy designs that attempt to increase risk perception to motivate adaptation response. One way to increase climate change risk perception is through persuasive risk communication strategy. For example, by providing persuasive information on climate change risk in a way that creates concern and by demonstrating potential measures that can be applied. The finding also suggests that the impact of persuasive risk communications may depend on the power of the information included in risk communication strategies. However, it is also clear that risk perception alone without access to adequate resource and information would not lead farmers to implement response measures. Therefore, adaptation-enhancing interventions should include both risk communication strategies and adaptation capacity improvements. One way to build farmers' adaptation capacity could be by increasing access to institutional services such as agricultural extension services that found to positively influence farmers decision to adapt. Additionally, targeted provision of climate change and adaptation information to groups that have less access is relevant. Overall improvements of the agriculture sector and technological interventions may help to increase the adaptation potential of farmers.

Table 1 Variables description and descriptive statistics of the sample

Variable name	Variable description	Proportion or Mean (SD*)	Expected effect
Adaptation decision	=1 if respondent indicates(plans) at least one adaptation measure, 0 otherwise	0.75	Dependent variable
Gender	=1 if male, 0 otherwise	0.80	(+)
Age	Age in years	44.8 (14.7)	(+)
Formal education	Respondent educational level (categorical) Coded as:		(+)
	1=None (ref.)	0.43	
	2=Primary	0.41	
	3=Secondary	0.14	
	4=Post-secondary	0.01	
Marital status	=1 if married, 0 otherwise	0.8	(+)
Household size	Number of family members	5.4 (2.5)	(+)
Farm size	Size of farm in hectare	1.6 (1.2)	(+)
Soil fertility status	Respondent self-reported farm soil status (categorical). Coded as:		(-)
	1=Very fertile (ref.)	0.03	
	2=Fertile	0.85	
	3=Infertile	0.11	
Agroecology	=1 if household is located in warm agroecology, 0 otherwise	0.66	(+)
Non-agricultural income	=1 if household has non-agricultural income sources, 0 otherwise	0.05	(+)
Credit service	=1 if household receives credit service, 0 otherwise	0.35	(+)
Agricultural extension service	=1 if household receives extension service, 0 otherwise	0.88	(+)
Irrigation water access	=1 if household lives in villages officially recognized to have irrigation water access, 0 otherwise	0.50	(+)

Yield reduction experience	=1 if household indicated experiencing yield reduction in at least one crop because of rainfall or temperature change in the past, 0 otherwise	0.56	(+)
Production shock experience	=1 if household indicated experiencing production shock in the two years preceding survey year, 0 otherwise	0.61	(+)

*SD=Standard deviation ** Ref.=reference category

Table 2 Farmers' planned adaptation measures

Planned adaptation measures	Percent of respondent
No plan	25
Tree planting and management	41
Irrigation related activity	17
Soil management and input	13
Income diversity (livestock and off-farm employment)	7
Livestock related activity	4
Crop diversity	4
Adjusting planting date	2
Others	3

Note: In the multivariate probit analysis, in the main equation of interest, the dummy dependent variable 'adaptation decision' is =0 if a respondent indicated no plan, and =1 if a respondent indicated any one or a combination of the other adaptation measures

Table 3 Estimates of the multivariate probit model of adaptation decision

Explanatory Variables	Adaptation decision (A)		Yield reduction experience (Y)		Production shock experience (P)	
	Coef.	P>z	Coef.	P>z	Coef.	P>z
Gender	.403	0.085*	0.126	0.604	0.093	0.682
Age	.005	0.392	-0.002	0.773	-0.013	0.044
Formal education						
Primary	.387	0.067*	-.035	0.856	-0.046	0.818
Secondary	.685	0.031*	.171	0.555	-0.142	0.626
Post-secondary	.126	0.864	-.384	0.613	0.217	0.763
Marital status	-.285	0.263	0.005	0.983	0.094	0.713
Household size	.104	0.010*	0.019	0.575	-0.033	0.331
Farm size	-.075	0.356	-0.179	0.020	0.004	0.955
Soil fertility status						
Fertile	-.491	0.355	-0.050	0.915	0.281	0.478
Infertile	-.417	0.480	-0.135	0.796	-0.19	0.673
Agroecology	-.368	0.077*	0.052	0.822	0.70	0.002
Non-agricultural income	.134	0.703	0.416	0.228	0.049	0.90
Credit service	.097	0.614	0.051	0.776	0.154	0.407
Agricultural extension	.787	0.001*	0.223	0.405	-0.503	0.048
Irrigation water access	-.013	0.947	-0.361	0.041	-0.175	0.344
Yield reduction	.008	0.980	-0.628	0.171		
Production shock	1.872	0.000*				
Constant	-.441	0.032*				
rho_{YA}	-.233	0.451				
rho_{PA}	-.932	0.000*				
rho_{PY}	.419	0.114				

Notes: N=263; log likelihood=-445.3; Wald chi^2=229.43; Prob>chi2=0.000; likelihood ratio test of rho chi2(3) =6.377; Prob>chi2=0.095; ***= significant at 1%; **= significant at 5%; *=significant at 10%

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