DRIVERS OF CLIMATE SENSITIVE FARM LEVEL ADJUSTMENTS: 
CLIMATE CHANGE, ECONOMIC AND TECHNICAL FACTORS, AND 
RESOURCE AVAILABILITY

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Summary

This thesis is aimed at contributing to an overarching research question of what new interventions are required in agriculture to adapt to climate change. In a similar manner to most previous studies, the thesis attempted to answer this question by examining how farmers are currently responding to climate change and the factors influencing the process or its determinants. Earlier studies have produced a long list of farm-level adaptations to climate change and their socio-economic determinants. However, the adjustments identified by the studies along with their determinants are not unique to climate change, and therefore do not indicate the importance of new interventions. For example, the commonly identified adjustments such as soil conservation and irrigation are already at the center of existing policies in agriculture. Likewise the importance of determinants such as access to credit and education which are singled out by the studies as key variables for adaptation are already at the hub of the literature on agricultural development.

Studies in the past have failed in suggesting distinct interventions, which are necessitated by climate change. I attribute this shortcoming to weak methodological approach in disentangling adjustments strongly motivated by climate change and to lack of appropriate typologies with implications on resource needs. Studies in the past often used an enquiry method that directly asks farmers to list their adaptation strategies. Such approach is susceptible to response biases, and does not also put non-climatic drivers in perspective. Farmers normally make adjustments simultaneously addressing multiple drivers. Therefore for an adjustment to be identified as an adaptation strategy, it should be shown that it is strongly liked to climate change than other drivers. This is particularly true for contemporary farmers who are responding for a number of drivers including market and technological dynamics.

Previous studies also treated all farm-level adaptations as one homogenous group of adjustments that are influenced by one set of determinants. This study, however, argues that adaptations that use traditionally used inputs, here called non-technological adaptation, should be separately examined, as they are likely to have distinctive resource needs. Examples could be changing planting date and crop diversification. While technological adaptations can benefit from the extensive literature on agricultural technology adoption in the last decades, non-technological adaptations can greatly benefit from further study as one distinct group of adjustments. In this Doctoral study, I employed a household survey of farm households in a district in central Ethiopia and attempted to address the existing flaws in the literature on farm-level adaptation in agriculture.
The first paper was aimed at identifying farm adjustments that are primarily motivated by climate change. A new methodological approach that puts non-climatic drivers in perspective while reducing the likelihood of response biases was applied along commonly used methods. It was shown that in the study area three adjustments are strongly associated to climate change: changing planting date, crop switching (changing crop type) and crop diversification. In the second paper, a second-round survey was carried out to closely examine crop switching as an adaptation strategy. I examined the permanent adoption and abandonment of crops by farmers in the last two decades. It was found that crop adoption is primarily induced by price changes while crop abandonment is strongly motivated by climate change. The trend of crop abandonment is also inline with predictions by studies on ecological change in climate change. In the third paper, I showed that non-technological adaptations are likely to be more dependent on accumulated farm experience than level of schooling and availability of finance. The major implication of this study, for our study area, is that non-technological adaptations such as changing planting date and crop switching are adjustments that are primarily induced by climate change.

The broader implication of my findings is that non-technological adaptations should be the primary focus of adaptation policies in agriculture. The findings implied that adaptation in agriculture is essentially the reallocation of resources accessible to a community. For which reason, accumulated experience of farmers on the broader community context like farming conditions could be instrumental. Since climate change just contracts or expands existing agro-ecologies without creating unique conditions, it is unlikely that new technological adoptions are necessitated by climate change. Therefore, mechanisms that facilitate non-technological adaptations such as experience-sharing sessions composed of farmers from diverse agro-ecologies and farming conditions can be vital for adaptation in agriculture. Our study also highlighted that mainstreaming climate change in farm adjustments primarily induced by non-climatic drivers can be crucial.
Zusammenfassung


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Chapter 1
Introduction

1.1. Background

Society has adjusted itself for millennia for both threats and opportunities. At the extremes, effective adaptation to opportunities have led to great civilizations, while inadequate adaptation to threats has resulted into the collapse of societies. The Egyptian civilization is the product of adaptation to the gradual desertification in the Sahara since 5600 B.C., which induced the convergence of various communities around the Nile giving rise to complex societies (Kuper & Kröpelin, 2006). In this case, the desertification was a blessing, or opportunity, in disguise. On the other hand, the collapse of the Easter Island in the 17th century is often attributed to environmental degradation, which can be an excellent case of poor adaptation to threats (de la Croix & Dottori, 2008).

Adaptation in agriculture has had a central place in society’s adaptation. Agriculture can be broadly defined as an economic activity that manages plant and animal species for the production of food, fiber and other products. Agriculture is estimated to have existed for more than 10 millennia providing two of the basic needs to humanity: food and clothing. Due to this central role in society, adaptation in agriculture used to determine the overall success of society for ages before the advent of the industrial revolution. The glory of ancient Egypt is highly attributed to success in agriculture that was made possible with wave of inventions starting from the plow to hydraulic irrigation (Janick, 2002; Kuper & Kröpelin, 2006). The rise of the Axumites in present day Ethiopia also coincided with increase in spring rainfall in the first century A.D. that increased agricultural production (Butzer, 1981). A millennium later, unsustainable intensification of agriculture in Axum contributed to its fall (Butzer, 1981, 2012). Similarly, the collapse of Mesopotamia is partially attributed to the problems of sedimentation and salinization that had detrimental impact on their irrigation-based agriculture (Jacobsen & Adams, 1958).

The most recent major adaptation in agriculture occurred as a response to opportunities created by technological innovation. A notable development is the Green Revolution in developing countries since the middle of the 20th century where over the last 50 years cereal production tripled although cultivated land only increased by 30 percent (Wik, Pingali, & Broca, 2008). The revolution is driven by the wide spread adoption of high-yielding varieties coupled with chemical fertilizers, irrigation and to some extent pesticides (Pingali, 2012). Although major improvement in agricultural productivity in the developed world took place much earlier, farmers in these regions are also undertaking significant adjustments to technological innovation. For example, the GMO revolution triggered one of the fastest adoption rate in
agriculture where the land covered by GMO seeds increased by 94-fold between 1996 and 2011, and about 43 percent of this land is in US (James, 2011).

Besides adapting to technological innovation, farmers have been adjusting to major changes such as land degradation, pests and diseases, and urbanization. Land degradation such as soil erosion and deforestation in the globe over the last half of the 20th century caused an estimated damage of over 231 billion USD or about 0.41 percent of global GDP in 2007 (Nkonya et al., 2016). Similarly, pests and diseases have become one of the most damaging shocks in agriculture (Sundström et al., 2014). For example, the outbreak of the foot and mouth disease (FMD) in Great Britain in 2001 resulted in 20 percent loss of the country’s farming income in the same year (Thompson et al., 2002). Addressing these two vital threats took a form of promoting improved soil and water conservation practices; integrated pest management; and development of veterinary services, among others. On the other hand, to exploit the benefits from high rate of urbanization, countries have designed strategies and policies that facilitate the transition from subsistence to commercial agriculture. Creating market linkage between smallholder farmers and markets has been a key area of focus in agricultural development (von Braun, 1995).

There is now one more major threat and in some cases opportunity for the agricultural sector: climate change. Crop yield losses as high as 5 percent per decade have been observed in the recent past, and losses of over 10 percent per decade are expected to become more likely beyond the middle of this century (Porter et al., 2014). Declines in livestock production are also often projected as a result of the effect of climate change on feed and water availability, and incidences of diseases (Porter et al., 2014). The negative impact of climate change is expected to be severe in tropical areas, which host the most vulnerable farming communities in the world. Nelson et al. (2009), for instance, estimates that climate change may increase child malnutrition in 2050 by about 20 percent. The impact of climate change in agriculture is mostly negative, but some areas in high latitudes may experience productivity gains.

A logically following question is, “the agriculture sector has already been adjusting to different drivers and what new interventions are needed to adapt to climate change?” Do we just need to keep on doing what is already being done through existing agricultural policies and institutions, or do we need new interventions? Answering this question has become the ultimate goal of numerous studies after the 1990s. A common approach adopted by most previous studies is to examine the ongoing process of adaptation by farmers and identify the factors that facilitate or impede it. This entailed identifying the adjustments made by farmers as a response to climate change and then investigating the correlation between the adoption of the adjustments and the socio-economic characteristics of farmers. The aim of these studies is
to identify the resource constraints in adapting to climate change and recommend interventions accordingly.

Survey-based studies that examine how farmers are responding to climate change have dominated the literature on adaptation in agriculture, where for example in 2015 they accounted nearly 40 percent of the research output (Davidson, 2016). The major finding of these studies is that farmers have perceived climate change and are already taking adaptive measures. The studies identified very diverse types of farm adjustments as adaptation strategies, including among others: changing planting date, tree planting, soil and water conservation, crop switching and irrigation (T. Deressa, Hassan, Ringler, Alemu, & Yusuf, 2009; Maddison, 2007; Tesfaye & Seifu, 2016). The studies also produced a diverse list of determinants, or resource needs, that are correlated to the adoption of these adaptation strategies. The commonly identified determinants are: level of schooling, land size, access to credit, access to extension, age of the household head, and distance to market (Adimassu & Kessler, 2016; Maddison, 2007; Rahut & Ali, 2017; Yong, 2014).

However, the results of most studies in the past have failed in indicating what new adjustments are triggered by climate change, and how we should facilitate them. The commonly identified “adaptation strategies” in previous studies are not new in any way and have already been the focus of agricultural development interventions for decades. Farm adjustments like crop switching, irrigation and soil conservation can be induced by land degradation, enhanced availability of technologies and market dynamics. Yet the majority of earlier studies do not provide adequate empirical evidence that they are particularly associated to climate change. Furthermore, the identified determinants such as access to credit and access to extension services have already been at the forefront of development interventions particularly to promote the adoption of new technologies (Foster & Rosenzweig, 2010). This is not, however, surprising as the adaptation strategies to which these determinants are identified are adjustments that have already been the focus of agricultural policies.

The lack of distinct or important findings in the literature on farm-level adaptation favored the concepts of adaptive capacity and vulnerability that can be applied to multiple stresses or drivers. Adaptive capacity is defined as the ability of a system to respond to stresses in the environment and is a function of farmers access to resources such as finance, technology, information, skill, and institutions (IPCC, 2001). Vulnerability can be conceptualized as a function of: exposure to hazards, sensitivity and adaptive capacity (IPCC, 2001). A suggested approach in the vulnerability literature is to couple climate change with other stressors in assessing exposure and sensitivity of a community in general for multiple stressors
Assessments of adaptive capacity of the community will then be combined with this information to suggest the required interventions to reduce the vulnerability of the community. The approach of these studies is that if we enhance the adaptive capacity of farmers to stresses in general, we can address climate change as well. These studies can be considered an improvement on farm-level studies I discussed earlier which do not consider multiple drivers in their investigations.

Yet treating climate change together with multiple stresses cannot be a panacea for lack of clear understanding on how farmers respond to climate change. We need to draw a clear causal link between climate change and farm adjustments to make specific policy recommendations that facilitate adaptation. For instance, a general theory that access to information enhances adaptive capacity cannot on its own suggest that the provision of information on changing planting date is required for adaptation. One first need to verify that changing planting date is an adaptation strategy and then examine what resources it requires.

The main goal of this thesis is to validly identify farm adjustments motivated by climate change and their resource needs or determinants, and by doing so to shed light on an overarching question of what new interventions could be necessitated by climate change in agriculture. I focused on two important gaps in the literature: methodological flaws in identifying adaptation strategies and lack of appropriate typologies in classifying them. Before delving into the specifics of the research questions, I first provided below a brief discussion of relevant theories and empirical background. The empirical background, that follows the theoretical background, is divided into three subsections, and each of them serves as a backdrop for each of the three studies, or contributions, that makeup the thesis.

1.2. Theoretical Background

Adaptation is defined by the IPCC (2014) as “the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities”. At the level of the individual, the scale of examination for this study, we are interested in how individuals make adjustments in response to the potential threats and opportunities posed by climate change. This topic can be viewed from different theoretical frameworks, particularly from economics, psychology, and the interdisciplinary fields of vulnerability and resilience. The following subsections summarize the relevant concepts from these fields, which culminates with discussion on how this study approaches its research problem against this backdrop.
1.2.1 Economics of adaptation

The expected utility theory from economics can be an excellent starting point to study adaptation. Following this theory, farmers are expected to make adjustment decisions as a response to climate change with the objective of maximizing their expected utility. When the effect of climate change is negative, the adjustments are supposed to reduce the harm as much as possible while in case of opportunities they are directed at fully exploiting them. According to this theory, we assume a rational farmer who is goal oriented and consistent in his/her decision-making. The rationality assumption also applies to poor farmers as was established by Schultz in the 1960s (Schultz, 1964). If we follow this normative theory from neoclassical economics, the problem will normally boil down to market imperfections. For adaptation, this will lead to the valuation of the social costs or benefits of climate change and ensuring that the same are signaled to markets.

The effects of losses from climate change, however, are likely to be more valued by farmers than gains. The law of decreasing marginal utility that assumes a concave utility function implies that a unit loss is likely to be valued more than a unit gain. This phenomenon is what is called risk aversion. Yet risk aversion cannot be fully explained by the expected utility theory. A seminal work by Kahneman and Tversky (1979) on prospect theory applied the concept of diminishing sensitivity from psychology to explain people’s loss aversion behavior. As per this theory, an individual examines decision options from a certain reference point as losses and gains. On the gain side concave value function explains his/her choices similar to the concept of decreasing marginal utility. Losses are, however, treated differently with convex value function with steeper slope. The implication on adaptation study is that losses from climate change are likely to be strongly felt by farmers relative to gains even more than suggested by the expected utility theory. Especially farmers in developing countries are known to be highly risk-averse (Hamal & Anderson, 1982; Yesuf & Bluffstone, 2009). Some argue that it is this risk aversion that perpetuates poverty by trapping farmers in low-risk and low-return agriculture (Dercon & Christiaensen, 2007). Risks posed by climate change may, therefore, exacerbate the welfare of such farmers by more than that can be accounted for by damages in crop yield or other outcomes.

1.2.2 The Psychology of adaptation

The loss-side of climate change, which is usually the case in agriculture (Porter et al., 2014), has also made psychological theories on humans’ response to risks very relevant in the study of adaptation. A notable mention is the socio-cognitive Model of Process model of Private Proactive Adaptation to
Climate Change (MPPACC) developed by Grothmann and Patt (2005). The framework was developed based on the protection motivation theory of Maddux and Rogers (1983) that has been widely applied in the study of patients behavior towards health threats.

As per the MPPACC, peoples’ (or actors’) perception of climate change risks and their adaptive capacity determine their adaptation intention and eventually their adaptation. The perception of risk is the function of actors’ perceived probability of exposure to climate change impacts and their assessment of the magnitude of the impact. Since there are many risk factors, actors’ appraisal of climate change risk relative to other drivers is considered the more relevant variable in inducing adaptation actions. Besides their risk appraisal, actors adaptation intention and action also depend on their evaluation of the efficacy of the available adaptation options; their own ability and the associated costs. The framework places the two important factors of actors risk and adaptation appraisal at its core while including relevant variables like social discourse, cognitive biases, maladaptation, and resources or objective adaptive capacity. Grothmann and Patt (2005) argue that perceived or subjective ability could be as important as objective ability or access to resources in influencing adaptation actions.

1.2.3 Resilience and Vulnerability

The hazard related concepts of resilience and vulnerability have also come at the forefront of the study of adaptation. These two system-oriented concepts have developed in separate research traditions over the years and integrating the concepts has been very difficult despite their use on similar research topics (Miller et al., 2010). Resilience is a concept that originated in the ecological sciences. It was first formulated to understand the process of recovery of ecological systems after a disturbance (Adger, 2006; Miller et al., 2010). Resilience is defined as the capacity of a system to preserve its essential structures and functions despite a disturbance, which depends on its capacity to adapt, learn and self-organize (Adger, 2006; Carpenter, Walker, Anderies, & Abel, 2001; Holling, 1973). The term “essential” is used here to denote that the recovery is not necessarily to an identical state before the disturbance. In fact, the resilience may result into a transition to a new state with more favorable functional attributes (Miller et al., 2010). These types of transitions are called transformational adjustments, in contrast to incremental ones. The concept has evolved in the last decades and is now applied in the study of socio-ecological systems (Carpenter et al., 2001). Yet an important critic against the resilience research tradition is its inclination to biophysical than social systems (Miller et al., 2010).
Vulnerability is a concept that studies the degree of susceptibility of systems to shocks or disturbances. The term has been used in very diverse fields ranging from economics, psychology to development studies. The use of the term in two closely related research traditions is particularly of interest to us. These are the research traditions related to natural hazard and sustainable livelihoods. The first research tradition originated in the studies of the susceptibility of society to hazards such as flood, drought and earthquake (Adger, 2006). This research direction has been primarily focused on integrating the exposure, sensitivity and adaptive capacity of social systems (socio-ecological systems in recent times) to assess their vulnerability (Adger, 2006; IPCC, 2001). Exposure is the likelihood of a particular community or social systems to be exposed to a particular hazard at present or in the future. Sensitivity is the degree of susceptibility of a system to the stimuli of a hazard. For example, an agricultural production system dependent on rainfall can be more sensitive to climate variability than the one that uses irrigation.

Adaptive capacity is the ability of a system to reduce or avoid the damages from a particular hazard by making appropriate adjustments. Adaptive capacity of a system is often viewed as the cumulative effect of the economic, social and biophysical characteristics of social systems such as level of schooling, access to finance, social capital and soil quality (IPCC, 2001; Karen O’Brien et al., 2004; K. O’Brien, Quinlan, & Ziervogel, 2009; Westerhoff & Smit, 2008). The common approach of this research field is that enhancing the adaptive capacity of systems based on vulnerability assessments can reduce the potential damage from the hazards. However, there exists a somewhat different discourse, defined as contextual vulnerability that defines vulnerability as the function of dynamic and multidimensional processes in contrast to the outcome-oriented conceptualization I just discussed (O’Brien, Eriksen, Nygaard, & Schjolden, 2007).

Vulnerability is also a key term used in the concept of sustainable livelihoods in the field of development studies, which is often used in the context of development cooperation and poverty alleviation (Adger, 2006). This research field has evolved from its predecessor entitlement theory that primarily focuses on the role of individuals’ access to resources or entitlements in society’s vulnerability to shocks like famine (Adger, 2006). The sustainable livelihood theory in its current form also places the role of livelihood assets, called capitals, at its core. A livelihood is sustainable if it “can cope with and recover from stress and shocks, maintain or enhance its capabilities and assets, maintain or enhance its capabilities and assets, and provide sustainable livelihood opportunities for the next generation” (Chambers & Conway, 1991). Resources can be classified into five as human, physical, social, financial and natural capital (Carney et al., 1999). Individuals will employ different livelihood strategies that employ these assets with the aim of achieving livelihood outcomes like increased income and reduced
vulnerabilities (Carney et al., 1999; Scoones, 1998). These livelihood strategies take place in two important contexts that also determine their success: vulnerability context and transforming structures and processes. Vulnerability context can be classified into three as trends, shocks and seasonality (Carney et al., 1999). Climate change can, therefore, be considered as one vulnerability context, either a trend or shock. Transforming structures and processes are the political, policy, institutional, cultural and business factors that determine individuals access to the five capitals and their vulnerability. The sustainable livelihood approach main line of argument is that poor people access to the five assets is the key factor that determines their extrication from poverty or their vulnerability.

### 1.2.4 Approach of this study

The preceding theories or concepts have supported the study of adaptation since its emergence in the 1990s (Donald, Adger, & Katrina, 2007), and this study relies at the same time improves on these conceptual backdrops. My approach is not to subscribe to only one of these theories but rather to use understandings from each of them as necessary, which will be more evident as you go through the rest of the thesis. Below, I summarize the key assumptions of this study and how it approaches its research problem.

This thesis assumes a rational decision maker who maximizes his/her expected utility. Simon’s theory of satisficing could be a more realistic way of maximization to assume in smallholder farmers setting (Patt & Gwata, 2002). According to this assumption, individuals make decisions by choosing the first alternative that satisfies much of their expectations rather than searching for the most optimal point. Either way, a farmer will probably make adjustment decisions as long as there is a major change in the environment like climate change. Evidences are accumulating over the past few decades that farmers have perceived climate change and are already responding to it (T. T. Deressa, R. M. Hassan, & C. Ringler, 2011; Glwadys Aymone Gbetibouo, 2009; Maddison, 2007; Tessema, Aweke, & Endris, 2013).

The thesis also puts the issues of resources at the core of its examination. One of the major aims of this study is to identify the distinct resource needs of farmers in adapting to climate change. The central role of access to resources in smallholder farmers context in the developing world has been strongly established in the past. The vast literature in agricultural technology adoption in the last decades has firmly established the importance of resources in agricultural development. Resources such as access to credit, level of schooling of farmers, access to extension services, and farm size have been shown to
strongly influence the process of technology adoption by smallholder farmers (Burton, Rigby, & Young, 1999; Doss & Morris, 2000; Foster & Rosenzweig, 2010; Wossen et al., 2017).

Resources, also called determinants, are here defined broadly as any asset or capital a farmer owns or has access to. Resources are what are called factors of production in economics. In the concept of vulnerability as defined by IPCC (2001), resources are equivalent to the adaptive capacity of farmers. For the resilience theory, which is more of focused on biophysical systems, finding the equivalent of resources is challenging. Klein, Nicholls, and Thomalla (2003) suggest considering resilience just as one component of adaptive capacity as defined by the vulnerability literature. For this study, I adopt the taxonomy of resources by a sustainable livelihood framework where five types of resources or livelihood assets are identified as human, physical, social, financial and natural capital (Carney et al., 1999). These are what are defined as objective adaptive capacity in the MPPACC framework. I employ the concept of MPPACC on the role of subjective adaptive capacity in this study. This is, however, only to a limited extent as can be seen in Chapter 2, and the focus of the study is primarily on the objective adaptive capacities of farmers.

My research approach attempts to improve on the limitations of the existing too risk-oriented approaches in the study of adaptation. It is true that climate change is more of a threat than an opportunity. However, a large majority of farmers in even developing countries are also adjusting to substantial levels of opportunities. For instance, in our study area in Ethiopia agricultural production increased annually on average by 7.6 percent in the last decade with productivity growth of about 2.3 percent per year. The high level of growth is partly attributed to opportunities created to farmers through improved extension services, better road connections and favorable market situations (Bachewe, Berhane, Minten, & Taffesse, 2015). The implication of this is that a typical smallholder farmer in Ethiopia has probably adjusted to opportunities more than he/she has done to threats. Therefore, the study of adaptation to climate change should be made in cognizant of this fact. This allows that our recommendations in relation to climate change can easily be tuned to the ongoing major development in the agricultural sector.

The conceptual frameworks that originate in the hazard and risk literature, however, do not give adequate focus to the positive developments in the smallholder context. Opportunities in the environment are treated merely as capacities to adapt. Such approach is needed for vulnerable communities, which are primarily adjusting to stresses or challenges in the environment. However, for many farmers even in low-income countries who are primarily responding to opportunities, it could be a too pessimistic approach to
the problem. It may even imply a problem of suboptimal risk aversion at higher scale where society does not fully exploit opportunities due to disproportionate attention given to risks.

In this study, I considered both the important threats and opportunities in Ethiopia. For instance, in the second contribution, Chapter 3, I observed an interesting interplay of market opportunities and climate change in adapting to climate change. Moreover, considering opportunities helped in disentangling the adjustments motivated by climate change. Linking climate change to farm adjustments is one of the major bottlenecks in the study of farm-level adaptation. The following section will elaborate on the methodological challenges in disentangling adjustments motivated by climate change and our approach. It will be an empirical background to the first contribution of the thesis in Chapter 2.

1.3. Which farm adjustments are adaptation strategies?

Identifying the farm adjustments that are primarily motivated by climate change is one of the two major goals of this thesis, the other being identifying resource needs. Drawing a clear link between farm adjustments and climate change should precede the examination of resource needs of farm-level adaptations. It is this line of thought that could bring us closer to determining the new interventions required by agricultural development policies to address climate change. For example, identifying changing planting date as an adaptation strategy implies that new interventions are required to adjust the traditional sowing dates of farmers, which is probably a new type of intervention necessitated by climate change. Changing planting date may also have implications on harvesting date, prices, and pesticide use, which all imply a need for mainstreaming or integrating it in the existing development programs. Therefore, what we should do differently because of a new and major change in the environment, here climate change, is clearly visible when we understand what new adjustments are strongly linked to it.

Linking climate change to farm adjustments, however, has become very problematic because farmers respond to multiple drivers simultaneously. Farmers especially in the contemporary world are living under a very dynamic environment. On one side, increased access to new technologies and new markets is creating new opportunities that entail farm adjustments. On the other side, threats or shocks like pest infestation, droughts, and land degradation are compelling farmers to take adaptive measures. A farmer makes an adjustment on his farm taking into account all these developments. The question is, therefore, not to identify adjustments that are solely motivated by climate change, but rather to identify the ones strongly induced by it in relative terms.
There are two ways to study the link between climate change and farm adjustments: cross-sectional regression modeling and survey enquiry. In the first method, farm characteristics are regressed on climatic, ecological and socio-economic variables across a region to infer how a change in climate will affect farm decision-making. The first step is to reveal how climate variables are correlated with the characteristics of farms such as crop and livestock choices. Then based on this correlation, inferences are made on how the expected future climate induces shifts from one farm type to another. For instance, S. N. Seo and R. Mendelsohn (2008) using a structural Ricardian model showed that the expected warmer climate in Africa will induce shifts from beef cattle to heat-tolerant goats and sheep.

Survey enquiry is so far the only available method to identify ongoing adjustments to climate change. Cross-sectional studies can only indicate the expected adaptations at present and in the future assuming that farmers will make the necessary adjustments. However, they do not provide any evidence that the adaptive measures are currently taking place and what factors influence them. Ideally, this could be inferred by having a panel data on farm characteristics that is long enough to capture climate change. However, to my knowledge there is no such data even in data-rich countries. The only option left to study the process of adaptation in real time is to rely on surveys that directly ask farmers how they have adapted to climate change.

Consequently, an increasing number of studies utilized surveys to identify farm-level adaptations to climate change. A major effort, probably the largest so far, is a survey on about 9,500 farm households in Africa by the Centre for Environmental Economics and Policy for Africa (CEEPA) from 2002 to 2004, which assessed the adaptation strategies of farmers in eleven African countries (Katharina Waha, Zipf, Kurukulasuriya, & Hassan, 2016). This survey identified diverse types of farm-level adaptation responses such as soil and water conservation, changing crop varieties, changing crop types, tree planting, shifting to non-farm activities, shortening growing season, and irrigation (Maddison, 2007). When one sees this list of adaptation strategies what immediately comes to mind is: aren’t these adjustments already taking place for many reasons including poverty alleviation, environmental conservation and enhancing agricultural productivity. Ethiopia was one of the countries studied by the survey where about 1000 farm households in the Nile Basin of the country were included. The survey showed that tree planting is the most frequently mentioned adaptation strategy (T. T. Deressa, Hassan, Ringler, Alemu, & d, 2009). My doubt on the validity of this finding has become the impetus for my first paper, Chapter 2.
After looking the findings of studies in the past, one may be curious to see how the data was collected. Here, I present part of the questionnaire used by the CEEPA survey in the following box (Katharina Waha et al., 2016):

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1. Have you noticed any long term shifts in the mean temperature on your farm? (please explain) ____________

2. Have you noticed any long term shifts in the mean rainfall on your farm? (please explain) ____________

3. What adjustments in your farming have you made to these long term shifts in temperature? Please list below? ___________

4. What adjustments in your farming have you made to these long term shifts in rainfall? Please list below. ____________
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I argue that such way of identifying adaptation strategies that has been widely applied in many studies (Bryan, Deressa, Gbetibouo, & Ringler, 2009; T. T. Deressa et al., 2009; Tessema et al., 2013) can result into spurious findings for two reasons. The first is the way the questions are structured is susceptible for response bias. If a farmer gives positive response to the perception questions (1 & 2), he/she may be inclined to respond positively for the adaptation questions as well just to avoid embarrassment by doing nothing for something perceived. This is what is called social desirability bias (SDB) (Fisher, 1993; Maryon & Gordon, 2000). SDB is a well-recognized cognitive bias and occurs when respondents are put in a position to be ego-defensive, or due to a general tendency of people to put themselves in favorable light (Fisher, 1993; Wåhlberg, Dorn, & Kline, 2010). The style of questioning in the CEEPA survey is even more susceptible to SDB when applied to adaptation studies. This is because most farm adjustments are linked to multiple drivers (Karen O’Brien et al., 2004; Smit & Wandel, 2006) and one can easily mention some adjustments as adaptation strategies even if they are not particularly associated to climate change. Rather than randomly mentioning an adjustment a farmer may also pick a sensible answer based on common media narratives like “tree planting is good for the environment”. I suspect that this phenomenon may have contributed to the identification of tree planting as the number one strategy in Ethiopia by the CEEPA survey.

The second drawback in the common style of enquiry, henceforth called the direct enquiry method, is that the questions are not made in a way that could show the influence of climate change relative to other
drivers. As I discussed earlier, an adjustment is associated to multiple drivers and identifying adaptation strategies to climate change is essentially identifying those, which are particularly related to climate change. Hence, unless one uses a method that can unravel the relative degree of linkage between adjustments and climate change, there could not be a logically sound basis to claim that some adjustments are adaptation strategies. For instance, a farmer can mention adopting a particular crop as an adaptation strategy even if it is primarily induced by new market opportunities.

Chapter 2, the first contribution of the thesis, will be devoted to address the two methodological drawbacks I just discussed and suggests a new methodological approach. The second paper, Chapter 3, builds on the findings of the first study and narrows down its focus to only one key adaptation strategy, crop switching (changing crop type). Crop switching is an interesting type of adaptation strategy in the study of links between climate change and farm adjustments; this will be the topic of the following section.

1.4. Range shifting crops and switching decisions

One can view agriculture as a managed ecosystem where different species are managed often in their natural setting. What makes the agricultural sector very susceptible to climate change is the fact that the managed species have distinct climatic requirements. Climate change is expected to affect the physiology and phenology of species (Hughes, 2000), and when certain thresholds are reached, range shift of species occurs. In natural systems, this will involve the gradual dispersion of species to new territories.

Ecological studies already established that many species in the wild are shifting or will shift their ranges pole wards and upwards in elevation due to climate change. A study by Kelly and Goulden (2008) in Southern California's Santa Rosa Mountains predicted that on average the dominant plant species shifted their range upwards in elevation by about 65m. Parmesan et al. (1999) based on a study of 35 non-migratory birds in Europe also showed that the majority of them (63 %) are expected to shift their ranges northwards by 35-240 km in this century. A major meta-analysis on over 2000 cases of species responses estimated that species have recently shifted their ranges towards higher elevations and latitudes at a median rate of 11.0 m and 16.9 km per decade respectively (Chen, Hill, Ohlemüller, Roy, & Thomas, 2011).

Ecological approaches have also been applied on agricultural crops to predict the potential impact of climate change on their geographical range. Rippke et al. (2016) projected how the nine major crop
species that account 50 percent of the food production quantity in sub-Saharan Africa shift their ranges in climate change. They found that three out of the nine crops will undertake major geographical range shifts. Particularly, maize and beans are expected to lose about 30 and 60 percent of their current suitable area respectively by the end of this century. Similarly, Tuck, Glendining, Smith, House, and Wattenbach (2006) predicted that the suitable climate space of temperate oilseeds, cereals, starch crops and solid biofuels in Europe will move northwards by 2080, while losing their southernmost ranges during the same period.

Crop species, unlike species in the wild, however need more than ecological modeling as their distribution depends on farm decision-making. In other words, socio-economic factors need to be considered along with ecological variables to examine the impact of climate change on crop distribution. Cross sectional studies that analyze the correlation between crop choices and climatic variables while taking into account socio-economic and ecological factors are effective ways of doing this. S. Niggol Seo and Robert Mendelsohn (2008a), for instance, based on a study of 949 farmers in seven South American countries projected that farmers will shift from maize, wheat and potatoes to fruits and vegetables as a result of a changing climate.

The range shift of crops is predicated on adjustment actions taken by farmers, particularly crop switching, to allow their “dispersion” into their optimal territories. Farmers need to either abandon their old crops and/or adopt new ones from adjacent agro-ecologies towards which the climate is shifting. Although routine it may seem, crop switching alone can substantially reduce the impact of climate change in agriculture. Pradeep Kurukulasuriya and Robert Mendelsohn (2008) estimated that the damage in agriculture in Africa could be reduced by more than 60 percent if farmers instantaneously adapt by switching crops. Similarly, Costinot, Donaldson, and Smith (2016) based on a global modeling study estimated that crop switching alone can more than halve the potential damage in agriculture by the middle of this century.

Studying crop switching as an adaptation strategy is crucial for two reasons. Firstly, the adjustment can significantly reduce the damage from climate change and hence we need to know the factors that accelerate the process. Secondly, expected crop switching can be inferred from ecological studies and this information can be used as a validation mechanism in identifying switching decisions primarily motivated by climate change. For example, in our study area sorghum is expected to shift its range upwards in elevation. It is, therefore, expected that it is increasingly adopted at its top most range as the climate changes. This information can be used in identifying which crop switching decisions are probably
motivated by climate change. This will be a key addition to the literature on adaptation for which identifying adaptation strategies has posed a major methodological bottleneck as I discussed in the previous section.

Crop switching as an adaptation strategy will be the topic of Chapter 3, the second contribution of the thesis. In this study, I investigated the determinants of crop switching in my study area. I examined crop switching at the level of individual crops, which reduces the risk of social desirability bias. Besides, I considered multiple drivers alongside climate change. Hence, it builds on the arguments in the preceding section while introducing a new approach of linking climate change to farm adjustments.

1.5. Typology and resource needs

Adaptation to climate change can take place at different levels or magnitudes of alteration with implications on resource needs. The most subtle adaptation response by a farmer can take place by modifying the allocation of land among the crops he/she grows. In this case, there is no new element entering the farm and the change will be only confined to adjustments on the allocation of inputs. These types of adjustments are what are called those in the intensive margin (Guo & Costello, 2009), in contrast to adjustments in the extensive margin that involve the introduction or abandonment of inputs altogether. These types of adjustments are less likely to be resource intensive and may just require the provision of information. On the other hand, some adjustments to climate change can be very resource intensive, as they require the adoption of new technologies and even sometimes a fundamental alteration of the farming system. The first types of adaptations can be called technological adaptation while the latter are known as transformational adaptations. Because of the high degree of alteration involved in such adjustments, they probably require the availability of diverse resources such as finance, education, land, wealth etc.

However, the use of appropriate typology with implications on resource needs is very limited in the adaptation literature. Studies often treat all farm-level adaptations as one homogenous group of adjustments with similar resource needs. For example, Maddison (2007) who studied the determinants of very diverse type of adaptation strategies ranging from changing planting date to fertilizer adoption concluded that, “Although experienced farmers are more likely to perceive climate change, it is educated farmers who are more likely to respond by making at least one adaptation”.

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The typology with resource implication that is sometimes used in the adaptation literature is: incremental versus transformational. Transformational adaptation is defined by IPCC as “adaptation that changes the fundamental attributes of a system in response to climate and its effects” (Field et al., 2014). When the scale of change is below a level that one may call fundamental, we will get the incremental adaptations. Most farm-level adaptation can be considered as incremental. Whether a farm changes planting date or adopts a new irrigation technology, the change does not fundamentally alter the farming system. Transformational adaptation can only happen in unusual cases, for example when a crop-growing farmer becomes pastoral solely depending on livestock production or when he/she leaves the agricultural sector altogether. Transformational adaptations are better conceptualized at higher scales such as at national or regional level where we can think of a number of transformational adaptations that may alter the structure and process of economic, social and political systems. The incremental category is too broad while the transformational one is less relevant for farm-level adaptation, hence calling for a new typology.

In this study, I introduced for the first time a new typology of farm-level adaptations with important implications on resource needs: technological versus non-technological. Technological adaptations are adjustments that use new technologies to the community of interest. This may include new crop varieties, chemical fertilizer and irrigation equipment. These types of adjustments are what are normally studied in the literature on technology adoption in agriculture over the last several decades. The adoption of technologies has been a key development agenda particularly in the developing world. Governmental and NGO efforts have targeted promoting the adoption of technologies with the aim of increasing agricultural productivity, enhancing food security and poverty reduction.

Non-technological adaptations are defined as those adjustments that employ old or well-diffused technologies in the community of interest. Examples may include changing planting date, crop switching, and crop diversification. For non-technological adaptations, we do not focus on introducing a new input or farming practice. Farmers just need to reallocate their existing inputs or adopt an input that has been used for generations in the vicinities of their farm. For instance, as an agro-ecology shifts to drier classifications, farmers need to shift to growing dry-land crops or modify their land allocation among existing crops. Such type of adaptations are expected to be less-resource intensive than technological ones. The topic of the distinct resource needs of non-technological adaptations will be the focus of chapter 4, third contribution of the thesis.

Non-technological adaptations, I argue, should receive special attention in adapting to climate change. Technology adoption has already been the major focus in the past and technological adaptations can
benefit from the well-established literature on the topic. Furthermore, climate change only contracts or expands existing agro-ecologies, and there has not been any evidence that unique agro-ecologies are created by it. This means that new technologies need not be discovered; we just need to diffuse what has already been there. When we superimpose the issue of adaptation to climate change on the existing policy and research focus, non-technological adaptations are the ones that stand out as the distinctive aspects of adaptation. A closer examination of non-technological adaptations could help answer the question: “what new interventions are needed to adapt to climate change?” Non-technological adaptations such as crop switching has also been shown to substantially reduce the damage from climate change (Costinot et al., 2016; Pradeep Kurukulasuriya & Robert Mendelsohn, 2008). In Chapter 4, I will scrutinize non-technological adaptations in the study area with the aim of revealing their distinctive resource requirements.

1.6. Contributions of the Thesis

Now, based on the empirical discussions in the preceding three sections, I summarize the three studies that makeup this thesis and their approaches.

The question of “what new interventions are needed to adapt to climate change in agriculture?” can be answered by identifying farm adjustments that are strongly linked to climate change and their resource needs. I attribute the failure in previous studies in addressing this research problem to two main reasons: methodological flaws and inadequate typology of adaptation strategies. On the methodological side, the approach of many studies in the past did not take into account multiple drivers in identifying climate induced adaptation strategies. A common approach was to directly ask farmers how they adapted to climate change, the direct enquiry method. This has not allowed unraveling the importance of climate change in inducing adjustments in relative terms to other drivers. Besides, I argued that the way the survey questions were structured is open to response biases, particularly social desirability bias. My first contribution, Chapter 2, is focused on this topic. It introduces a new methodological approach, which addresses the drawbacks in earlier studies. The new approach examines the correlation of farmers’ rating of drivers with their choice of farm adjustments. It assumes that farmers who rate climate change higher are also likely also to make adjustments that are strongly linked to it. In this study, farmers rate climate change as a driver side-by-side with other drivers, hence the method considers multiple drivers. Besides, farm-level adaptations are identified by indirect inference based on correlation of two separately made enquiries on drivers and adjustments, hence minimizes the risk of response biases. I applied the new method on a study area in Ethiopia along with the direct enquiry method and one more alternative method.
that uses direct ranking of drivers by farmers for each farm adjustment. The study attempts to draw a clear link between climate change and farm adjustments by comparing the results of the three alternatives methods.

Building on my findings in Chapter 2, in Chapter 3 or second contribution of the thesis, I narrow down to one adaptation strategy, crop switching, to clarify its link to climate change and identify its determinants. Crop switching is identified in Chapter 2 as one of the adjustments that are probably induced by climate change. It is also one of the most important adaptation strategies that can substantially reduce the damage from climate change in agriculture (Costinot et al., 2016; Pradeep Kurukulasuriya & Robert Mendelsohn, 2008). I investigated how the different drivers influence the adoption and abandonment of individual crops with the aim of disentangling the ones stimulated by climate change. Such in-depth examination allowed me to draw a clear link between climate change and crop switching decisions. Besides, a peculiar feature of crop switching is that it can be inferred from ecological predictions. Many crops are expected to shift their geographical range as their suitable climate space shifts in climate change. Predictions on the nature of this ecological change can, therefore, serve as a validation mechanism in identifying crop switching decisions that are likely to be induced by climate change. After identifying the crop switching decisions strongly motivated by climate change, I examined the socio-economic factors influencing the process, or its determinants.

An important gap in earlier studies is inadequate typology of adaptation strategies. They often considered adaptation strategies as a homogenous group of adjustments and attempted to produce a single set of resources they require. This is, however, an erroneous approach as the characteristics of adaptation strategies greatly vary as well as their resource needs. Particularly, we need to have a typology of farm-level adaptations that delineates technological adaptation from the other types of adjustments. The adoption of technologies has always been at the heart of agricultural policy throughout the world. Consequently, the process of farmers’ adoption of new technologies has been extensively studied in the past. It is likely that technological adaptation and its resource needs are very similar to this process and can also benefit from its literature. Furthermore, I discussed in the preceding section that it is less likely that adaptation necessitates the adoption of new technologies. However, adaptation can also take place without adopting a new technology, I introduced the term “non-technological” to differentiate these types of adaptations. The separate examination of non-technological adaptations can provide important insights on the distinct resource needs of adaptation. In previous studies, both technological and non-technological adaptations have been examined together and I argue that this particularly over-shadowed the distinctive resource requirements of non-technological adaptations. This topic will be the focus of Chapter 4, third
contribution. In this study, I compare the determinants of four farm-level adaptations to climate change. Two of them are non-technological while the other two are technological.

1.7. Methods

1.7.1 Study Region

The impact of climate change in agriculture is quite heterogeneous across regions (Porter et al., 2014). Studies in general predict consistently negative effect on crop yields in low-latitude countries. Predictions for northern latitudes, however, may be negative or positive depending on the region. The impact of climate change in low-latitude regions, which are home to the most vulnerable population in the world can particularly result into dire consequences. A systematic review of agronomic studies by Knox, Hess, Daccache, and Wheeler (2012) showed that Africa and South Asia, the two most food insecure regions, may experience about 8 percent decline in the yield of their eight major crops by 2050 due to climate change. Wheat in Africa and maize in South Asia particularly bear the brunt of climate change suffering about 17 and 16 percent loss respectively during the same period.

For this study, I selected a developing country in lower latitude as a study region, Ethiopia. Ethiopia is one of the places in the world where climate change is likely to be strongly felt by farmers for two reasons. Firstly, the climate of the country is characterized by erratic rainfall, and recurrent occurrences of droughts and floods (UNDP, 2007). The projected rise in temperature in the country by about 1.1°C in 2030 (UNDP, 2007), therefore, may exacerbate this situation. Particularly, drought has been the topmost important hazard in the country for ages, the earliest record being in the 250 BC (Webb, von Braun, & Yohannes, 1992). Secondly, agriculture in Ethiopia is characterized by low-technology use and high dependency on rainfall, and is run by economically poor farmers. All these features of the agriculture sector in Ethiopia make it very susceptible to climate change. Conway and Schipper (2011) put the country as an extreme example of high vulnerability to climate change in Africa.

The high agro-ecological diversity in Ethiopia provides a unique opportunity in the study of farmers’ adaptation to climate change. This is because the effect of climate change in agriculture essentially works through the range shifts of crops or agro-ecological zones (AEZ) (Cho & McCarl, 2017; Kala, Kurukulasuriya, & Mendelsohn, 2012; Rippke et al., 2016). For instance, about 30, and 60 percent of the land currently cultivated with maize and beans respectively in sub-Saharan Africa is expected to be unsuitable for these crops by the end of this century (Rippke et al., 2016). Kala et al. (2012) also showed
that climate change may expand drier and less productive AEZs in Africa. Hence, the agro-ecological diversity in Ethiopia can provide several cases of AEZ shifts, along with associated cases of farm adjustments.

The climate in Ethiopia is induced by altitudinal gradient due to its position at the most prominent mountain system in Africa (Hurni, 1998). The highest point is Mt Ras Dashen with 4620 m above sea level (asl) and an average temperature of less than 0° c, and the lowest point is in the Danakil Depression at about 125 m below sea level and with an average temperature of 34.5° c (Darrah et al., 2013; Dinar, Hassan, Mendelssohn, Benhin, & others, 2008). Based on the traditional climate typology in the country the places between these two points are divided into 5 types of AEZs: Bereha (desert) below 500 m asl; Kolla (lowland) 500-1500 m asl; Weynadega (middle land) 1500-2300 m asl; Dega (highland) 2300-3200 m asl; and Wurch (frosty zone) above 3200 m asl (Hurni, 1998). The agricultural production system in Ethiopia can be broadly classified as the mixed crop-livestock production system in the highlands and the pastoral system in the lowlands. The former is the dominant production system in the country employing about 90 percent of the population (MoARD (2004) cited in EEA, 2005) where a typical farmer owns about 1.4 ha of land (ERSS, 2013), and grows crop while keeping some farm animals like cattle, sheep, goat and poultry. The latter production system is practiced by pastoral and agro-pastorals residing in desert and semi-desert areas of the country.

1.7.2 Study Area, Sampling and Survey

For this study, I selected Semien Shewa Zone of the Amhara National Regional State of Ethiopia which is positioned at the central plateau of the country between 8°42’40” N to 10°46’40” N latitude, and 38°36’54” E to 40°6’13”E longitude. It is located at about 130 km north of Addis Ababa, the Ethiopian capital. Mixed crop-livestock farming is the dominant production system in the zone where the major crops grown are teff, maize, wheat, sorghum and barley which are also the major crops grown in the country (CSA, 2013; Ege, 2005). Besides, the administrative zone encompasses the four major agroecological zones in the country making it a very representative study area for farming conditions in Ethiopia.

From the Semien Shewa Zone, I purposively selected Ankober district from among the 24 Woredas (districts) in the administrative zone. The district is selected because it encompasses the typical AEZs in the Semien Shewa Zone and in Ethiopia. The district is strategically positioned at an escarpment that gently slopes down in to the Great Rift Valley. It is one of the edges of the extensive plateau in central Ethiopia. At its western side the elevation reaches over 3,700 m asl, Mt Kundi, while the elevation
gradually decreases as one moves eastwards reaching well below 1300 m asl, in about 20 km of Euclidean distance (Lulekal, Asfaw, Kelbessa, & Van Damme, 2014). This allowed the district to encompass four of the five AEZs in the country. The remaining one AEZ, Bereha (desert) is dominated by pastoral production system, which is not the focus of this study.

Ankober district encompasses all the AEZs in the country that are primarily characterized by mixed crop-livestock farming. The total land area of the district is about 700 km2 and hosts a population of over 80,000 people where over 90 percent of them live in rural areas (Lulekal et al., 2014). A typical farm household, with about 4 to 5 family members, has nearly 1 ha of land (Own survey in 2015). The commonly produced crops are teff and sorghum in Kolla (lowland) and Weynadega (middlelands), and barley in Dega (highland) and Wurich (frosty zone) (Own survey in 2015). On average a farm household owns 4 cattle, 5-7 goats or sheep, and 1 donkey (Own survey in 2015). Oxen are used as source of drought power for tilling. Sowing, weeding and harvesting are mainly performed manually., Most farmers, about 90 percent, have adopted chemical fertilizer (Own survey in 2015). There is one major growing season called Meher season, which depends on a rainy season that starts around the beginning of June. There is also an erratic growing season around March, called Belg, where only less than 10 percent of the land cultivated in the Meher season is used to grow short season crops like barley and potato (Own survey in 2015).

Among the 18 Kebeles, the lowest administrative unit, in Ankober I purposively selected three Kebeles for this study: Alyuamba-zuria, Hagereselam and Laygorebela. The first two are characterized by Weynadega (middle land) and Kolla (lowland) agro-ecology respectively. Laygorebela is predominantly of Dega (highland) climate but also has some villages in the Wurch zone. This Kebele is used to select households both in Dega and Wurch (frosty zone). Two household surveys were carried out; the first from December 2014 to Feb 2015, and the second from January to February of 2016. I also held one focused group discussion at each of the four AEZs in the three Kebeles. The second survey was carried out as a continuation of the first one with the aim of a closer look on crop switching as an adaptation strategy, which is the topic of the third chapter.

The first survey used a sample of 270 farm households, which was allocated among the four AEZs in the three Kebeles in approximate proportion to the land coverage of the AEZs in Semien Shewa Zone. However, for Wurch, which encompasses only a very small share of land, I used a sample size of 30, which is the minimum size that could give statistically sound results as per the central limit theorem. Kolla and Dega each received 60 households, while in Weynadega 120 households were sampled. For
the second survey, 190 of the 270 initially sampled households were included. The sample size of 30 remained the same for the Wurch (frosty zone) while for Kolla and Dega I selected 40 households from each. The remaining 80 households were from the Weynadega zone. The households were selected using systematic random sampling technique.

1.7.3 Data collection and analysis

The survey was carried out using interview schedules (see the appendix), which were administered by nine enumerators. I used both descriptive and inferential statistical techniques. Descriptive techniques included percent, mean, and standard deviation. Inferential statistics included Friedman test, Wilcoxon signed rank test, Sign test, multivariate probit and logit. The first three are non-parametric statistical techniques that were used for ordinal scale variables.

1.8. Structure of the Thesis

This cumulative thesis contains five chapters including this chapter. Each of the subsequent three chapters, chapter 2 to 4, is devoted to each of the three contributions of the thesis. Chapter 5 synthesizes the key findings of the three contributions, which ends with policy implications. The chapter suggests potential areas of interventions specifically in Ethiopia and in general in smallholder context. The interview schedules used by this study are attached in the appendix.
Chapter 2
Climate change as a motivating factor for farm-adjustments: rethinking the link

Yibekal Abebe Tessema, Jonas Joerin, Anthony Patt

Abstract

In order to design effective adaptation policies for the agricultural sector, it is important to understand what adjustments farmers actually make in order to cope with climate change. Many studies have compiled lists of such adjustments, especially in the developing country context. There is reason to believe, however, that such studies have suffered from methodological flaws, with the result of over-attributing the importance of climate change, relative to other factors leading farmers to alter their behavior. In this study, we examined the potential for such a bias, by incorporating a new methodological approach, side-by-side with the more established ones, in a household survey undertaken in Ethiopia. We found evidence of such a bias in the application of one of the established methods, the direct-enquiry method. That method identified fertilizer application as the most frequently adopted climate adaptation. Other methods, however, indicate that this and other farm-level adjustments, while compatible with climate change, have actually very little to do with it, and instead are primarily motivated by new market and technological opportunities. Our new methods reveal a list of climate adaptations that is somewhat shorter than previous studies have found. This could allow for more effective and efficient sets of policies to help farmers best adjust to new threats and opportunities.

Key words: climate change; adaptation; farm-adjustment; multivariate probit model; social desirability bias; Ethiopia

2.1 Introduction

Understanding farm-level adaptation responses to climate change has developed into an important area of research, owing to its relevance in the design and execution of effective adaptation strategies at national and regional scales. There is a growing literature identifying farm-level adaptation responses, or simply adaptations, to climate change. For example, studying eleven African countries Maddison (2007) identified the following farm-level adaptations: changing crop varieties, soil conservation, changing crop type, tree planting and adoption of irrigation. Other lists, often overlapping, have been identified in other studies (e.g. Alauddin & Sarker, 2014; Below et al., 2012; T. Deressa, R. M. Hassan, & C. Ringler, 2011; Hassan & Nhemachena, 2008; Tessema et al., 2013).
The methods used in previous studies to identify farmers’ response to climate change, however, have some potential flaws. They have typically failed to consider adaptation in the context of diverse drivers of farm-level actions, and maybe over-attribute concerns about climate change as a causal factor. In addition, they may have been influenced by social desirability bias: the observed phenomenon that survey respondents tell researchers what the respondents think the researchers want to hear. Given that many farmers are aware that researchers are looking for a long list of adaptations, farmers will identify actions that they are taking as adaptations to climate change, even if climate change is not an important driver. Even when researchers ask farmers to rank the relative importance of different drivers, there is reason to believe that farmers will overstate the relative important of climate change for their actions.

In this study, we investigate these potential flaws. Focusing on farm-level actions undertaken in Ethiopia, we attempt to disentangle the relative importance of climate change and other drivers. We believe that in doing so, we can gain a more accurate picture of the factors that lead farmers to adopt new practices. Even if interventions need to simultaneously address multiple stresses (Karen O’Brien et al., 2004; Westerhoff & Smit, 2008), it is vital to draw a clearer link between adjustments and their drivers. This is key to make sure that adjustments that particularly address climate change are not overlooked in the existing policy frameworks, which are probably more tuned to the long-established topics such as technology adoption, and land degradation. Similarly, our results can better inform the question of whether it is appropriate to spread funds that are earmarked for adaptation across all actions commonly viewed as adaptations, when the range of actions actually related to climate change may in fact be more limited. In this case, it may be possible to focus such funds on a narrower set of farm-level responses. Finally, our result could facilitate adaptation planning that builds on farmers’ efforts on the ground which has been shown to be more effective than a policy direction prescribed through a top-down approach or simply relying on 'techno-managerial expertise' (Mikulewicz, 2017).

2.2 Background

The IPCC (2014) has defined adaptation as “the process of adjustment to actual or expected climate and its effects.” Adaptation to climate change in agriculture has become crucial, especially for the vulnerable societies of the developing world that heavily rely on the sector (Nelson et al., 2009). Without effective adaptation, climate change has the potential to significantly reduce agricultural productivity, which may lead to serious repercussions on food security in the developing world (Nelson et al., 2009). For instance, losses in crop yield attributed to climate change in Africa and South Asia for eight major crops, which
account 80 percent of crop production in the regions, is estimated at 8% by 2050 relative to a baseline of 1961-1990 (Knox et al., 2012).

One can view farmers as utility maximizers (Duflo, 2006; Schultz, 1975), who make decisions to maximize net benefits by reducing potential losses from adverse events, and by increasing gains from new opportunities. Under a subsistence-farming situation, a more likely decision-making strategy could be ‘satisficing’, where farmers simply choose the first alternative that satisfies certain basic criteria (Patt & Gwata, 2002). In both cases, farmers’ decisions depend on their perception and evaluation of a multitude of opportunities and threats simultaneously occurring in their environment. On the one hand, they act in response to opportunities, including improved infrastructure, institutions, and markets. Improved road connectivity, for instance, may lead to substantial changes in a farmers’ input and output mix (Dorosh, Wang, You, & Schmidt, 2010). On the other hand, farmers also adjust their practices as a response to new threats, including land degradation, pests, or climate change. Within the wide range of new practices that farmers may adopt in response to new opportunities and threats, the ones that we can view as adaptations are those that are motivated by a concern about today’s climatic conditions or their changes in the future.

The livelihood framework (Ellis, 2000) matches this view of farmers’ decision-making. Livelihood strategies depend on households’ access to resources, and how these are used in the context of trends and shocks. The framework identifies five sets of resources: human, physical, natural, financial, and social. Access to each is determined or modified by social relations, institutions and organizations. Trends include changes in population, technology, relative prices, and macro policy. Shocks include events such as droughts, floods, pest outbreaks, disease, and civil war.

Based on the livelihood framework, one can identify eight potential drivers of farm-adjustments in Ethiopia: changes in input demand or price, changes in agricultural extension systems, changes in infrastructure, land degradation, changes in output demand or price, climate change, natural hazards (including pests and diseases), and changes in internal household characteristics. For example, changes in the relative prices of agricultural commodities and inputs directly affect the relative profits of different cropping decisions, which can lead to a range of adjustments. For instance, between the years 2002 and 2006, the relative prices of important agricultural commodities in Ethiopia showed continuous rise (Shimeles & Delelegn, 2013), with associated adjustments on the part of farmers. Threats like land degradation may also have an important role in inducing adjustments at farm-level. The cost of land degradation in Ethiopia, for example, is estimated to account at least 2-3 % of the country’s GDP annually (World Bank, 2007).
The concept of vulnerability that has evolved towards a system-oriented examination of socio-ecological systems could also provide an effective platform to study farm adjustments (Adger, 2006). The IPCC defines vulnerability as “the propensity or predisposition to be adversely affected” (IPCC, 2014). Vulnerability can be conceptualized as a function of exposure, sensitivity and adaptive capacity (IPCC, 2001). The exposure-sensitivity nexus represents the degree to which people are facing stress events and the susceptibility of the nature of their livelihood to be adversely affected by them (IPCC, 2001; Westerhoff & Smit, 2008). Adaptive capacity, on the other hand, stands for the ability or power of people or systems to make adjustments to cope with adverse changes in their environment (IPCC, 2001; Westerhoff & Smit, 2008). The Adaptive capacity and exposure-sensitivity of people or related systems is influenced by various biophysical, socioeconomic and institutional factors (IPCC, 2001; Karen O’Brien et al., 2004; K. O’Brien et al., 2009; Westerhoff & Smit, 2008). Whether farmers make farm-level adjustments can, therefore, be defined as a function of factors in their environment that can be linked to their exposure-sensitivity and adaptive capacity. These include their environmental changes, type of livelihood, household characteristics, and access to institutions.

The literature on vulnerability has also recognized the need to consider adaptation to climate change in the context of the complex interaction of other global changes or stresses (Karen O’Brien et al., 2004; Smit & Wandel, 2006; Westerhoff & Smit, 2008). This is an essential development as interventions are rarely designed to address climate change alone (Noble et al., 2014; Smit & Wandel, 2006). In fact, it has been shown that interventions that do not place adaptation in the framework of the complex interaction of climatic and non-climatic stresses may even be maladaptive (Westerhoff & Smit, 2008). On the other hand, adaptation to climate change is not necessarily confined to the adverse effects of climate change and also includes actions required to exploit the opportunities from climate change when available. Adapting to climate change should, therefore, be considered within the intertwined issues of vulnerability, and development planning.

To effectively integrate adaptation to climate change within the existing policy frameworks, it is useful to understand how farmers are responding specifically to climate change in the context of the different socio-economic and environmental changes. Within the adaptation literature, there has been a particular focus on the relationship between climate change and farm-level adjustments, one that does not differentiate between the different drivers. Most of the studies undertaken to date (e.g., Alauddin & Sarker, 2014; Bryan et al., 2009; Tessema et al., 2013) have used direct-enquiry methods: conducting interviews with farmers, directly asking them what measures he or she has taken to adapt to climate change.
change. This approach can easily overstate the importance of climate change as a motivational driver since the question is not framed in relative terms to the influence of other drivers. Other researchers have asked farmers to rank the various drivers (Mertz, Mbow, Reenberg, & Diouf, 2009). This direct ranking method ought to identify the relative importance of climate change, as long as one assumes that farmers’ responses are unbiased. Finally, there are studies that have identified adaptations by modeling the set of actions that would improve yields under conditions of climate change. These studies, however, fail to show whether these set of actions are currently taking place or not (S. Niggol Seo & Robert Mendelsohn, 2008b; Wang, Mendelsohn, Dinar, & Huang, 2010).

The commonly used method of direct-enquiry in most previous studies did not reveal the importance of climate change relative to other drivers in causing adjustments. A farmer may relate diverse types of adjustments to climate change even if the causal link is only strong for a few of them. This has potentially allowed the list of adjustments mentioned by farmers as adaptation responses to be long and diverse. Adjustments that are often studied in relation to land degradation, technology adoption, or pest management have been mentioned as adaptation responses. The lists of adaptation according to these studies have included, among others, fertilizer application, irrigation, soil conservation, and changing crop variety (T.T. Deressa, Hassan, Ringler, Alemu, & Yesuf, 2009; Glwadys Aymone Gbetibouo, 2009; Maddison, 2007).

There is also a particular behavioral bias that could play an important role in previous studies. This is social desirability bias: a response bias in surveys where individuals respond inaccurately to avoid embarrassment or to generate positive impression in the surveyor (Fisher, 1993). The bias occurs when individuals have to respond either on socially sensitive issues such as politics, environment or religion, or on personal matters such as dietary behavior and drug use (Grimm, 2010). Klesges et al. (2004), for instance, showed that social-desirability bias in a dietary survey led to downward bias in self-reports of food intake, and upward bias in physical activity. Leggett, Kleckner, Boyle, Dufield, and Mitchell (2003), in an environmental valuation study, also found that surveys on willingness to pay for nature conservation could be overstated due to the same bias. The bias has been well recognized in survey-based studies especially in the health literature, and various techniques have been developed in the past to overcome it. These techniques range from training interviewers (Grimm, 2010), indirect questioning (Fisher & Tellis, 1998) and adjusting measurements to account for the bias (Saunders, 1991).

Social desirability bias could have played a role in the adaptation literature to date. In the direct-enquiry method, the fact that questions on adaptation are often preceded by positive response on perception of
climate change may lead to this effect. This is because farmers may identify adaptations that they have taken in order to avoid the embarrassment of admitting that they have failed to respond to perceived problem. Social desirability bias may also manifest itself in respondents’ inclination to mention adjustments that are commonly seen as sensible, like tree planting, even when such an adjustment is in fact entirely motivated by other concerns. This problem can affect both the direct-enquiry and the direct-ranking methods.

We hypothesize that social desirability bias and lack of mechanism to reveal the relative importance of climate change have led to two undesirable outcomes: (1) they have led to an overestimation of the importance of climate change for many of the farm level adjustments that farmers are making, and, correspondingly, (2) they have led to identifying more farm-level adjustments as being climate adaptations than actually are. If one corrects for social desirability bias, we hypothesize, one would come up with a list of adaptations that is significantly shorter. With this shorter list, one could in turn focus adaptation funding more narrowly, and help farmers do a better job responding to the threats of climate change, where these threats are important. A more accurate list also reveals a better understanding of farmers’ adaptation to climate change with implications on required interventions. At the same time, we could do a better job of integrating farm-adjustments to climate change in the existing policy frameworks on vulnerability and economic development.

2.3 Methods

This study introduces a new methodological approach that not only considers different drivers, but also gathers data in a way to minimize social desirability bias. To do so, we analyze the correlation between farmers’ specific choice of adjustments and their rating of climate change as a driver for adjustments more generally. We assume that farmers who rate climate change relatively high are more likely to adopt adjustments strongly motivated by climate change. This is inline with the socio-cognitive Model of Private Proactive Adaptation to Climate Change (MPPACC) developed by Grothmann and Patt (2005) where climate change risk appraisal is a major factor that determines adaptive actions. We use the new approach alongside the direct-enquiry and direct ranking methods. This makes possible the comparison of the different results, and allows us to see how the new method yield results that may be different from the older ones.

We apply the three methods to identify farm-level responses in Semien Shewa Zone, Ethiopia. Based on national level mapping of climate change, it can be inferred that rise in temperature has been observed in
the study area between 1984-2006 (Jury & Funk, 2013). The changes in precipitation cannot, however, be precisely established relying on the same source. The study area is located in central Ethiopia, and lies between 8°42’40” N to 10°46’40” N latitude, and 38°36’54”E to 40°6’13”E longitude. It has a total population of about 1.8 million people and covers 15,936 km² of land (CSA, 2007). The study site encompasses areas falling in the major agro-ecological zones of the country having areas classified as Kolla (lowland, altitude 500-1500 m a.s.l.), Weynadega (middleland, 1500-2300 m a.s.l.), Dega (highland, alt 2300-3200 m a.s.l.) and Wurch (frosty zone, above 3200 m a.s.l.) lands. The major crops grown in the study area are teff, maize, wheat, sorghum, and barley, which are the major cereals produced in Ethiopia (CSA, 2013; Ege, 2005). The Semien Shewa Zone is subdivided into 24 Woredas (districts). For this study, Ankober Woreda was purposively selected primarily because it encompasses the 4 major agro-ecological zones, as well as the production of the full set of common cereals. From the 18 Kebeles, the smallest administrative unit in the Woreda, three Kebeles were purposively selected that represent the four agro-ecological zones of interest.

We used a semi-structured interview schedule that was developed based on information from a pilot survey and pre-testing. The total sample size, 270, was proportionately assigned to each of the four agro-ecological zones based on their share in the total land area of Semien Shewa. Dega and Kolla each are allotted a sample size of 60, Weynadega took 120, and Wurch 30. A list of farm households from the records of sampled Kebeles’ administrative offices was used to select households using systematic random sampling.

The interviews collected data on a number of variables, informed by our literature review. For the adjustments, we gathered data on the actions that farmers had taken in the last ten years. We used open-ended questions asking farmers to list their adjustments. To relate adjustments to potential drivers, however, we used a list of typical drivers in the region, based on a literature review and pre-testing. The literature review had identified a list of eight potential drivers of farm-level adaptations. We gathered data on farmers’ perceptions of these drivers and their relative importance, both in general terms and in relation to specific adjustments that farmers may have taken. In asking farmers to rate the general importance of different drivers for their collective set of adjustments, we used a five-point rating scale, ranging from strongly agree (5) to strongly disagree (1). In asking farmers to rate the importance for each individual adjustment, we used a three-point scale (high, medium, and low). These ratings were placed before any specific questions on climate change to avoid response biases.

To analyze the data, we engaged in three consecutive steps:
1. Identifying farm-level adaptations based on the direct-enquiry method, taking into account farmers' explanation on how the claimed adaptation assist in adapting to climate change;

2. Identifying farm-level adaptation responses based on the direct-ranking method, taking into account farmers’ rating of the degree of influence of potential drivers in bringing about farm adjustments; and

3. Identifying farm-level adaptations to climate change by fitting a Multivariate Probit (MPV) model to farmers rating of climate change as a specific driver for farm-adjustments in general (FRCD) as an explanatory variable, among others, and the dependent variables of farmers' choices of adjustments.

Across steps 1 – 3, we used a number of descriptive statistics, non-parametric statistical techniques, and an econometric model. To analyze farmers’ rating of the influence of potential drivers of farm-adjustments, we used non-parametric techniques that are suited to ordinal data (McCrum-Gardner, 2008). These are the Friedman test, Wilcoxon signed rank test, and Sign test. We used the first two tests to compare the rating of climate change against each of the other potential drivers. We used the Sign test to verify the results of the Wilcoxon signed rank test, which assumes normal distribution of differences between paired rankings. The Sign test does not make such assumptions (STATA Corp, 2013). We used a standard Multivariate Probit (MPV) model according to Greene (2003). In our study, binary variables represent farmers’ choice of farm adjustments where the variable takes the value of 1 if adopted by a farmer, and 0 otherwise. The model was estimated using the simulated maximum likelihood method (Cappellari & Jenkins, 2003). Multicollinearity was checked using the Variable Inflation Factor (VIF). In our study, since farm-adjustments can be either complementary or substitutable among each other, the MVP model could provide efficient estimates as it relies on a multivariate distribution (Lin, Jensen, & Yen, 2005; Nhachena & Hassan, 2007). The model has been used both in climate change adaptation research (Nhachena & Hassan, 2007) and other studies that involve multiple choice situations (Choo & Mokhtarian, 2008; Gibbons & Wilcox-Gok, 1998). The number of draws taken for the MVP for our study is 5, the default. But for such low number of draws, the model results could vary based on the random-number of seed used in the iteration process (Cappellari & Jenkins, 2003). To address this shortcoming, the model was repeated varying the random-number seed. Furthermore for further verification, the model was rerun reducing the number of dependent variables to 4 and a draw of 50 was taken which is a safe value for the number of equations included (Cappellari & Jenkins, 2003).
One can hypothesize that the choice of farm-adjustments depends on the agro-ecological zone where a farmer lives (Feder & Umali, 1993a), but it is problematic to associate each adjustment with a particular climate zone beforehand. Older farmers are more experienced and could adopt farm-adjustments, while on the other hand they can also be more risk averse and hence, slow in adoption (Adesina & Baidu-Forson, 1995; Gwadys Aymone Gbetibouo, 2009). Therefore, for age no particular relation is hypothesized. The education level of a farmer is expected to positively influence his implementation of farm-adjustments by increasing his capacity to acquire and process information (Adesina & Baidu-Forson, 1995; Maddison, 2007; Schultz, 1975). Large land and family sizes are hypothesized to positively affect the adoption of farm-adjustments as they represent higher access to labor and land resources (Croppenstedt, Demeke, & Meschi, 2003; Polson & Spencer, 1991). Access to extension services and credit is expected to be positively associated with the likelihood of making farm-adjustments through the provision of information and skill, and necessary capital for acquisition of technologies, respectively (CIMMYT, 1993; Polson & Spencer, 1991). Finally, access to markets improves a farmer’s access to information (Maddison, 2007), and increases the profitability of new practices or technologies (Foster & Rosenzweig, 2010). We, therefore, hypothesize that distance to markets is inversely related with the adoption of farm-adjustments.

The critical explanatory variable for the MVP model is farmers’ rating of the importance of climate change as a driver (FRCD). We also included a second potential driver, namely the rating of output demand as a driver of adjustments. We interpret a significant relationship between the FRCD variable and a specific adjustment as an indicator that climate changes is in fact the primary motivator of that adjustment.

2.4 Results

In this section, we analyze our data following the three steps described in the methods section.

2.4.1 Analysis using the direct-enquiry method

The first step of our research was to draw a link between farm-level adjustments and climate change, in a manner consistent with most of the current adaptation literature, and hence potentially subject to biases. Figure 1 shows the main adjustments that farmers identified as climate adaptations, in response to an open-ended question. The most frequently mentioned adjustment is
fertilizer, followed by vegetable production, soil and water conservation, tree planting, and changing planting date.

Figure 1 Main farm-adjustments to climate change based on the direct enquiry method (n=270). Other adjustments include: pest and disease management, changing sowing method, crop diversification, off-farm work, use of technology, market oriented production, changing harvesting time, crop rotation, and water harvesting.

Figure 2 How respondents justified their claimed-adaptations, in percent of respondents who mentioned at least one justification
Also as part of the direct enquiry method, we asked each farmer to explain how his or her most important adjustment actually helped in adapting to climate change. Across all of the adjustments, 73.6% of the respondents identified, one way or another, how the adjustment helped them to deal with a particular change in climatic conditions: changes in temperature, precipitation, or seasonality. Of these, many also volunteered how the adjustments would help them for reasons independent of climate change as well: boosting their productivity (14.4% of all respondents), or improving their sales revenue (4.9% of all respondents). The remaining 26.4% of respondents could not draw a link between their most important “adaptation” and climatic conditions, but only to an independent motivating driver: productivity, sales revenue, climate mitigation, or disease resistance. Figure 2 shows the particular adjustments for which non-climate factors (including climate mitigation) played the largest role. In one case, for the adjustment of animal rearing and fattening, respondents were more likely to list a non-climate driver than a change in climatic conditions as the justification for the action. What the results seen in Figure 2 suggest, as we will return to later, is the possibility that the initial list of adaptations (seen in Figure 1) could in fact be prone to bias. At least some of the adjustments listed, when turned to in depth, may have been undertaken for other reasons, at least by some of the respondents.

2.4.2 Analysis using the direct-ranking method

In addition to their answers to the open-ended questions, reported on above, farmers filled in a matrix defined by a closed list of seven adjustments and five drivers. For each of the adjustments, farmers rated the importance of the driver as either high (3), medium (2), or low (1).

Table 1 shows how the mean rating for climate change compared to each of the non-climate drivers: a negative number indicates that climate was on average rated as less important, while a positive value indicates that climate was rated as more important. We used the Wilcoxon signed-rank test to examine the null hypothesis that the rating given by respondents for climate change as a driver for a specific adjustments is equal to the rating given for the other variables. Most of the values are significantly different from 0, indicating that climate was either more or less important than one of the other drivers. Across the table as a whole, there are nineteen cases where climate appears to be significantly more important than another driver, five cases with no significant difference, and four cases where climate appears significantly less important. Looking at the adjustments separately, there is only one case – changing planting date – where climate significantly outranks all four of the other drivers. In four cases, climate change significantly outranks three of the drivers, but there is one driver with an insignificant difference, meaning that one cannot reject the hypothesis that this driver is equally important to climate change. In two of the cases – soil and water conservation, and use of fertilizer – at least one other driver
significantly outranks climate. For the latter of these cases, three of the other drivers significantly outrank climate.

These results begin to suggest more clearly that the initial direct enquiry method may have led to biased results. Indeed the adjustment listed most frequently as a response to climate change – fertilizer application (see Figure 1) – shows up as precisely that adjustment for which several other drivers appear to be more important than climate.

Table 1 Results of the Wilcoxon signed-ranks test for Ho: Rating of climate change = rating of another driver

<table>
<thead>
<tr>
<th>Farm-adjustment</th>
<th>Extension</th>
<th>Land degradation</th>
<th>Natural hazards (disease and pest)</th>
<th>Trends in demand or price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changing planting date</td>
<td>10.312***</td>
<td>11.790***</td>
<td>11.10***</td>
<td>10.811***</td>
</tr>
<tr>
<td>Crop diversification</td>
<td>5.544***</td>
<td>5.891***</td>
<td>2.724***</td>
<td>0.626</td>
</tr>
<tr>
<td>Tree planting</td>
<td>3.553***</td>
<td>0.801</td>
<td>9.870***</td>
<td>3.640***</td>
</tr>
<tr>
<td>Changing crop varieties</td>
<td>3.339***</td>
<td>11.083***</td>
<td>5.048***</td>
<td>0.692</td>
</tr>
<tr>
<td>Changing crop type</td>
<td>2.339**</td>
<td>10.557***</td>
<td>7.231***</td>
<td>-0.734</td>
</tr>
<tr>
<td>Soil and water conservation</td>
<td>-0.640</td>
<td>-3.276***</td>
<td>11.768***</td>
<td>11.32***</td>
</tr>
<tr>
<td>Use of fertilizer</td>
<td>-11.304***</td>
<td>-3.397***</td>
<td>3.319***</td>
<td>-5.891***</td>
</tr>
</tbody>
</table>

* *, ** and *** respectively indicate level of significance of 10%, 5% and 1%, and values are in bold only where climate change is rated higher.

2.4.3 Analysis using the new methodological approach

The results seen in Table 1 provided some evidence that drivers other than climate change have played a major role for a number of adjustments. All of these adjustments, however, were ones that farmers typically had listed as responses to climate, meaning that any questions about them could be susceptible to response biases. In a further methodological step, we asked farmers to rank the importance of the eight drivers (including climate) for all of the farm adjustments made within the last decade. The rating of climate change was then correlated using the MVP model to the adoption choice of farmers in the same decade. This new methodological approach assumes that farmers who rate climate change higher are
more likely also to adopt those adjustments strongly linked to climate change. By allowing farmers to rate climate change side-by-side with other drivers, the new method allows the rating of climate change to be relative. Since farmers do not have to specifically relate each adjustment to a driver, the method has the potential to minimize social-desirability bias. Therefore, this approach is anticipated to work better than the other two alternative methods. The MVP model was run with 7 farm-adjustments as dependent variables, where each adjustment is a dummy variable (1 if adopted and 0 otherwise). In addition to FRCD, 10 explanatory variables are included in the model (Table 2). The MVP model (Table 3) has in general reasonable prediction power (Wald Chi2 (70) = 223.70, probability > chi2 = 0.001). Error terms across equations are correlated (chi2 (21) – 112 and probability > chi2 = 0.0001), which justifies the use of a multivariate model.

Table 2 Description of explanatory variables

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Mean</th>
<th>S.D.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Agro-climatic zone</td>
<td>1.21</td>
<td>0.90</td>
<td>Ordinal based on altitude: 0=if Kolla, 1=Waynadega, 2=Dega, 3=Wurch</td>
</tr>
<tr>
<td>Age of the household head in years</td>
<td>49.13</td>
<td>14.24</td>
<td>Continuous</td>
</tr>
<tr>
<td>Level of education</td>
<td>0.47</td>
<td>0.50</td>
<td>Dummy, takes the value of zero if illiterate and one otherwise</td>
</tr>
<tr>
<td>Land owned in ha</td>
<td>0.97</td>
<td>0.68</td>
<td>Continuous</td>
</tr>
<tr>
<td>Family size</td>
<td>4.49</td>
<td>2.14</td>
<td>Continuous</td>
</tr>
<tr>
<td>Access to extension service</td>
<td>14.35</td>
<td>12.23</td>
<td>Dummy, takes the value of zero if without access and one otherwise</td>
</tr>
<tr>
<td>Access to credit</td>
<td>0.41</td>
<td>0.49</td>
<td>Dummy, takes the value of 0 if without access and one otherwise</td>
</tr>
<tr>
<td>Walking distance from market in hours</td>
<td>1.51</td>
<td>0.90</td>
<td>Continuous</td>
</tr>
<tr>
<td>Rating of climate change as a driver for adjustments (FRCD)</td>
<td>4.06</td>
<td>0.83</td>
<td>From 1 to 5; 1=very low, 2=low, 3=medium, 4=high, 5=very high</td>
</tr>
<tr>
<td>Rating of trends in output demand or price as a driver for adjustments</td>
<td>3.87</td>
<td>0.88</td>
<td>From 1 to 5; 1=very low, 2=low, 3=medium, 4=high, 5=very high</td>
</tr>
</tbody>
</table>

As described in the methods section, we reran the model varying the random seed and number of dependent variables included, and the model gave consistent estimates. Multicollinearity is not a problem for our model as the VIF values for the explanatory variables are all less than 10(1.07-1.34). The sign of the coefficients of the significant variables in each equation are in line with our initial hypothesis explained in the methods section, suggesting the reliability of the model.
FRCD, our key variable, is positively associated with changing planting date \((p < 0.05)\), crop diversification \((p < 0.01)\), and changing crop type \((p < 0.05)\). Hence, one can interpret these three adjustments as being strongly motivated by climate change. Soil and water conservation is also correlated to FRCD with relatively low level of significance \((p < 0.10)\), and it could have some weak relation to climate change. Tree planting, use of fertilizer and changing crop variety are not correlated with farmers’ rating of climate change as a driver for adjustments. Farmers’ rating of trends in output demand was negatively associated with the adoption of tree planting \((p<0.05)\) while it is positively correlated with the adoption of fertilizer \((p<0.05)\).

Table 3 Results of the MVP model. * and ** and *** respectively indicate level of significance of 10%, 5% and 1%. PLD=changing planting date, CRDV=crop diversification, TREE=tree planting, SWC= soil and water conservation, FERT=fertilizer, CRVR=changing crop varieties, CRTY=changing crop type

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>Farm-adjustments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>PLD</td>
</tr>
<tr>
<td>FRCD</td>
<td>0.306**</td>
</tr>
<tr>
<td>Agro-climatic zone</td>
<td>0.342**</td>
</tr>
<tr>
<td>Age of household head</td>
<td>-0.007</td>
</tr>
<tr>
<td>Level of education of the household head</td>
<td>-0.097</td>
</tr>
<tr>
<td>Land holding in ha</td>
<td>0.206</td>
</tr>
<tr>
<td>Family size</td>
<td>0.024</td>
</tr>
<tr>
<td>Access to extension</td>
<td>-0.315</td>
</tr>
<tr>
<td>Access to credit</td>
<td>0.357</td>
</tr>
<tr>
<td>Distance from market</td>
<td>-0.213*</td>
</tr>
<tr>
<td>Rating of output demand as driver for adjustments</td>
<td>0.108</td>
</tr>
<tr>
<td>Constant</td>
<td>-0.293</td>
</tr>
</tbody>
</table>

*, ** and *** respectively indicate level of significance of 10%, 5% and 1%

The direct-ranking and the new method of correlating FRCD to adjustment decisions gave comparable results, while the results of the direct-enquiry method are very different from the other two methods. The direct-ranking and the new method are similar in all respects except on changing crop varieties and tree planting. The two methods are comparable in identifying changing planting date and crop diversification
as adaptation measures. Changing crop type is identified in the new method as an adaptation response while it is moderately associated to climate change in the direct-ranking approach. The two methods are also similar in rejecting fertilizer, and soil and water conservation, although the latter is marginally linked to climate change in the new method. The major difference between the two methods lies on the fact that tree planting and changing crop varieties are highly associated to climate change in the direct-ranking method whereas they are not in the new method.

2.5 Discussion

The aim of this study is to identify the farm adjustments that are strongly motivated, in relative terms, by climate change by improving the methodological flaws exiting in the literature. It was initiated with a proposition that methods applied in earlier studies are prone to overestimating the importance of climate change as a factor motivating farm adjustments. Based on a case study in Ethiopia, we demonstrated that this is actually the case. Our results suggest that climate change plays limited role in several practices commonly listed as farm-level adaptations. Using an improved methodological approach, we showed that changing planting date, crop diversification and changing crop type are the adjustments that are strongly motivated by climate change in the study area. Hence, these adjustments in the study area are key adaptation strategies to climate change and should be given due emphasis in adaptation planning.

We compared the results of three alternative methods of identifying farm-level adaptations to make inferences on their relative reliability. The results of the direct-ranking method and the new approach are very comparable whereas the direct-enquiry method gave very different list of adaptation responses. The distinct results of the direct-enquiry method can be attributed to its design that does not define adaptation response in relative terms to non-climatic drivers and the susceptibility of its approach to social-desirability bias. By far the most important adaptation response according to this method is fertilizer application followed by vegetable production. Fertilizer is an important technology that has been behind significant gains in productivity in Ethiopia, and elsewhere in the world (Khush, 1999; Quiñones, Borlaug, & Dowswell, 1997). Therefore, associating it particularly to climate change is very contentious. A good number of farmers also justified their use of fertilizer and vegetable production in relation to improvements in sales revenue and productivity. It seems that farmers mention adjustments that are simply improving their profit as adaptation responses, a bias which could have been reduced if farmers were enquired by putting non-climatic drivers like trends in price in context.
Our findings also implied the potential effect of social desirability bias in using the direct-enquiry method. Tree planting and soil and water conservation are identified by the method as the third and fourth important adaptation responses to climate change. Tree planting, and soil and water conservation are highly promoted by the Ethiopian public extension system as part of a national program on watershed and forest development (ATA, 2015). It is, therefore, possible that farmers’ responses are influenced by social-desirability bias. The fact that some respondents justified these two adaptation responses in relation to mitigating climate change reinforces this possibility.

A major finding in the study is that the direct-ranking method and the new approach gave very comparable results even if they utilized different variables and followed very different approaches. This comparability partially validates both methods. However, it is reasonable to prefer the new methodological approach because of its design that reduces responses biases. The only important difference between the two methods is on tree planting and changing crop variety, which are identified as adaptation responses in the direct-ranking method while they are not in the new approach. Tree planting as shown earlier is an adjustment that can be favored by social-desirability bias if farmers have to relate it directly to climate change. However, it is problematic to explain the difference of the methods with respect to changing crop variety. Finally, both methods rejected fertilizer application as an adaptation response and rather associated it with trends in demand of agricultural commodities and the public extension systems. This finding is inline with a number of previous studies on fertilizer adoption that underlined the significance of the two drivers (Crawford, Kelly, Jayne, & Howard, 2003; Gurara & Larson, 2013).

The adaptation responses we shortlisted in this study have also been identified by a number of previous studies (e.g. T. Deressa et al., 2011; Maddison, 2007). Most previous studies produced a long list of diverse farm adjustments as adaptation responses while in this study we narrowed down to only few of them. As we have argued earlier, response biases and neglect of other drivers could have lead to the incorporation of many diverse adjustments in these studies. According to our results, interventions should support changing crop type, changing planting date and crop diversification, as they are important adjustments in relation to climate change. There is a need to ensure that adjustments that are particularly associated to climate change are adequately emphasized in adaptation planning. Finally, the farm adjustments considered in this study are only confined to those taking place on the farm. Yet farmers could take adaptive actions through off-farm employment, trading etc. The interpretation of our findings should be made putting this limitation in perspective.
Chapter 3
Crop switching as an adaptation strategy to climate change: the case of smallholder farmers in Ethiopia

Yibekal Abebe Tessema, Jonas Joerin, Anthony Patt

Abstract

The geographical range of agricultural crops is shifting due to climate change. Reducing the negative impact of this shift requires efficient crop switching at farm level. Yet there are scant studies that examine how crop switching is currently taking place, and what factors facilitate the process. And even these few existing studies often based their analysis on inadequately established causal link between climate change and switching decisions. Our study examined crop switching with the aim of identifying the specific switching decisions that are primarily motivated by climate change, and their determinants. The study employed a household survey on 190 households in Semien Shewa Zone in Ethiopia. Subjective rating of farmers was used to identify the relative importance of climate change in motivating the different types of switching decisions. A Logit model is used to identify determinants of crop switching decisions primarily induced by climate change. Farmers in the study area are currently abandoning certain crops as a response to climate change. The adoption of new crops is, however, mainly attributed to price changes. Most farmers who abandoned at least one crop adopted a crop called mung bean mainly due to its price advantages. As expected, crop switching as an adaptation strategy is more prevalent particularly in drier and hotter AEZs. The logit model showed that crop switching is strongly correlated with land size and agroecology. An important implication of the study is the need to integrate opportunities such as positive price changes in adaptation planning while giving proper emphasis to agroecological differences.

Keywords: crop switching, climate change, adaptation, determinant, logit, Ethiopia

3.1 Introduction

Major shift is projected in the suitable climate space of many crops across the globe due to climate change (Rippke et al., 2016; S. Niggol Seo & Robert Mendelsohn, 2008a; Wang et al., 2010). This phenomenon is similar to the range shift of plant species pole wards, or upwards for elevation-induced climate zones. Many species have recently shifted their ranges towards higher elevations and latitudes at a median rate of 11.0 m and 16.9 km per decade respectively (Chen et al., 2011). Similarly, the geographical range of...
agricultural crops is expected to shift. In Sub-Saharan Africa, the area suitable for maize and beans, two of the nine major crops in the region, is predicted to shrink by about 30 percent and 60 percent, respectively, by the end of the 21st century (Rippke et al., 2016). These shifts entail transformational adaptations such as substituting maize with more drought resistant crops like sorghum and millet (Rippke et al., 2016).

To avoid or reduce the potential loss in crop yield due to shifts in climate spaces, farmers need to make appropriate adjustments particularly crop switching. Global modeling studies suggest that two-thirds of the potential damage from climate change in the agricultural sector can be avoided by effective crop switching (Costinot et al., 2016). We define crop switching here to consist of two types of adjustments: (i) starting the adoption of a new crop for the first time, and (ii) abandonment of existing crops. Therefore, the term switching is better understood at plot level rather than farm-level, i.e., adopting a new crop doesn’t necessarily mean abandoning existing ones, and vice versa.

Studies in the past have examined the process of crop switching as an adaptation response and the factors that facilitate it. Most of these studies focused on revealing whether farmers are adapting by switching crops, and what type of socio-economic and environmental factors influence the process (Bryan et al., 2013; T. Deressa et al., 2011; Glwadys Aymone Gbetibouo, 2009; Maddison, 2007). These studies often consider crop switching just as one type of adaptation response without attempting to disentangle the specific types of switching decisions that are primarily motivated by climate change. This can be considered a key gap in the literature because certain types of switching decisions could be caused by non-climatic drivers such as price (S. Niggol Seo & Robert Mendelsohn, 2008a). Moreover, earlier studies do not give appropriate focus to non-climatic variables (e.g. Below et al., 2012; Fosu-Mensah, Vlek, & Manschadi, 2010; Gbetibouo, Hassan, & Ringler, 2010). Crop switching, however, takes place in the context of different drivers such as markets dynamics, pest occurrence, and land degradation. The consideration of such drivers is, therefore, vital to understand the relative importance of climate change in switching crops.

Few studies partially addressed the common methodological gaps in the literature. Alauddin and Sarker (2014) identified the determinants of a specific category of crop switching decision (adopting water-saving non-rice and horticultural crops) in a study area in Bangladesh. This is a major improvement from previous studies as it singles out one narrowly-defined type of switching decision as an adaptation strategy to climate change. The study, however, did not adequately clarify the basis for identifying the specific strategy as an adaptation response. Mertz et al. (2009) identified climate-induced crop adoptions
in their study area in Senegal. An important contribution of the study is the fact that it categorizes adoption decisions at the level of individual crops, i.e., as adoption of millet, maize, etc. Unfortunately, the study relied on a small sample size and did not analyze the determinants of the short-listed crop switching decisions strongly induced by climate change.

Our study builds on the works of Alauddin and Sarker (2014), and Mertz et al. (2009) to identify the specific types of crop switching decisions induced by climate change and their determinants. We first examine crop-switching decisions specific to the level of individual crops with the aim of identifying the determinants of the specific crop switching decisions primarily motivated by climate change. Our examination of crop switching in detail at the level of individual crops enables validating our results based on predictions from studies on crop distribution modeling and ecological change. This is a key addition to the literature on farm-level adaptations in general where the link between climate change and farm adjustments is still unclear. The identification of the socio-economic and environmental determinants of crop switching is also vital to suggest interventions that could facilitate it. Our study uses a household survey in Semien Shewa Zones of Ethiopia. The results could, however, be relevant for planning adaptations that target smallholder farmers in developing countries in general.

3.2 Methods

The study area, Semien Shewa Zone, is one of the administrative zones of Amhara Regional State of Ethiopia. It is located in the central highlands of the country; covers 15,936 km² area of land; and hosts about 1.8 million people (CSA, 2007). We purposively selected Ankober Woreda (district), which is one of the 24 districts in the administrative zone. Ankober district is selected as it encompasses the typical crop production systems and Agro-Ecological Zones (AEZs) in Semien Shewa Zone (CSA, 2013; Ege, 2005; Hurni, 1998). The district is found on an escarpment that stretches across four common AEZs, according to the traditional climate typology in the country: Kolla (lowland, altitude 500-1500 m a.s.l.), Weynadega (middle land, 1500-2300 m a.s.l.), Dega (highland, 2300-3200 m a.s.l.) and Wurch (frosty zone, above 3200 m a.s.l.) (Hurni, 1998). Three Kebeles (Laygorebela, Alyuamba Zuria, and Hagereselam), the lowest administrative unit, were selected from the 18 Kebeles in the district, making sure that all the 4 AEZs are included (Figure 3). There are two growing seasons in the study area: Meher (depends on rainy season from June – September), and Belg (rainy season from March to April) (Tanto Hadado, Rau, Bitocchi, & Papa, 2009). Meher is the main growing season in the country (Tanto Hadado et al., 2009).
A total sample size of 190 is proportionally allocated among the four AEZs based on their coverage in the study area, Semien Shewa Zone. For the Wurch, however, which is a rare AEZ in the study area (Ege, 2005; Hurni, 1998), we allotted a sample size of 30 based on the central limit theorem. Kolla and Dega each were allocated a sample size of 40 while Weynadega took 80. Systematic random sampling was used to sample households from the selected three Kebeles. The study also made use of data collected in an earlier survey (in 2014/15) on the same households.

Figure 3 Map of the study area, Ankober district. Central positions for the AEZs in sampled Kebeles, the smallest administrative area, are indicated with dots labeled as frosty (Wurch), highland (Dega), Middleland (Weyandega), and Lowland (Kolla) following the traditional climate typology in Ethiopia.

The rural household survey was conducted in January and February of 2016, and the data collected are for the immediately preceding growing seasons. To collect the data, a semi-structured interview schedule was used. The first key area of enquiry was the types of crops permanently adopted or abandoned by farmers over the last 20 years. For each of these crop switching decisions, respondents were asked to identify the first and second most important drivers from a list of six potential drivers: climate change, pest and disease, price change, soil erosion, and changes in intra household characteristics. The interview schedule clearly defined climate change for respondents to differentiate it from short-term weather variability. The non-climatic drivers are selected based on their potential importance in Ethiopia (Eshte, Mitiku, &
Shiferaw, 2015; PPSE, 2008; Shimeles & Delelegn, 2013; World Bank, 2007). Respondents were also given the option to mention other drivers incase the list is not exhaustive enough for them.

Table 4 Descriptive statistics for explanatory variables

<table>
<thead>
<tr>
<th>Explanatory variable</th>
<th>Mean</th>
<th>S.D.</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of the household head in years</td>
<td>50.71</td>
<td>13.70</td>
<td>Continuous</td>
</tr>
<tr>
<td>Land owned in ha</td>
<td>0.95</td>
<td>0.47</td>
<td>Continuous</td>
</tr>
<tr>
<td>Family size</td>
<td>4.41</td>
<td>2.12</td>
<td>Continuous</td>
</tr>
<tr>
<td>Walking distance from market in hours</td>
<td>1.53</td>
<td>0.92</td>
<td>Continuous</td>
</tr>
<tr>
<td>Level of education</td>
<td>0.44</td>
<td>0.50</td>
<td>Dummy, 0 if illiterate and 1 otherwise</td>
</tr>
<tr>
<td>Access to extension services</td>
<td>0.93</td>
<td>0.26</td>
<td>Dummy, 0 if without access, and 1 otherwise</td>
</tr>
<tr>
<td>Access to credit</td>
<td>0.38</td>
<td>0.49</td>
<td>Dummy, 0 if without access, and 1 otherwise</td>
</tr>
<tr>
<td>Access to irrigation</td>
<td>0.15</td>
<td>0.36</td>
<td>Dummy, 0 if without access, and 1 otherwise</td>
</tr>
<tr>
<td>Number of relatives (an estimated number of blood relatives in the village)</td>
<td>24.16</td>
<td>24.84</td>
<td>Continuous</td>
</tr>
<tr>
<td>Agro-Ecological Zones (AEZ)</td>
<td>2.30</td>
<td>0.96</td>
<td>Ordinal, 1 if Kolla (lowland), 2 if Weynadega (middle land), 3 Dega (highland), and 4 Wurch (Frosty)</td>
</tr>
</tbody>
</table>

Descriptive statistical methods of frequency, and bar graphs are used to describe the crop-switching process and its relation to climate change. A binary regression model (logit) is applied to analyze the relation between farmers’ crop switching decision, those specifically linked to climate change, and the socio-economic and environmental context of farmers.

The explanatory variables for the logit model are selected based on empirical evidence on their importance in influencing farm adaptation responses in particular, and farm-decision making in general. The hypothesized relationships of the explanatory variables with crop switching along with their descriptive statistics are given below (also see Table 4).
The age of a farmer is hypothesized to be positively associated with crop switching because older farmers are more experienced and have a better chance of perceiving and adapting to climate change (Maddison, 2007). Since switching crops is expected to occur primarily through locally available inputs, we expect that the role of farm experience is pronounced. Larger land and family sizes represent more land and labor resources at the disposal of a farmer, and are, therefore, expected to relax the resource constraints thereby facilitating any adjustment (Alauddin & Sarker, 2014; Croppenstedt et al., 2003; Shikuku et al., 2017; Yong, 2014), and hence positively influence switching crops. Particularly, larger land size allows farm experimentation, which may particularly accelerate crop switching. Farmers living close to markets are expected to be in advantage in accessing information (Maddison, 2007), while enjoying a relatively wider switching option with better prospect for profitability (Foster & Rosenzweig, 2010). Therefore, we hypothesize that distance from market is inversely related to switching of crops. Better schooling is hypothesized to positively influence switching crops as it may enhance access to information along with the complementary skills of processing it (Adesina & Baidu-Forson, 1995; Foster & Rosenzweig, 2010; Tan, 2014). Access to extension services is hypothesized to facilitate any adjustment including switching crops as it avails information including on climate change (Falco, Yesuf, & Kohlin, 2011; Maddison, 2007; Nhemachena & Hassan, 2007).

Improved access to credit has been shown to positively influence the adoption of agricultural technologies (CIMMYT, 1993; Feder & Umali, 1993b). Even if switching crops is less likely to be capital intensive, we expect positive correlation of access to credit with switching crops. Access to irrigation can influence switching crops either directly by increasing the types of crops grown on a farm, and potentially indirectly through its linkage with wealth. The number of relatives is used as a proxy for social capital that is expected to positively influence adjustment by switching crops. Social capital can be directly related with access to information, and facilitates learning new practices (Bandiera & Rasul, 2006). Finally, farmers in drier and hotter AEZs are more likely to take adaptation measures than those in humid climates (T.T. Deressa et al., 2009). Therefore, we expect more cases of crop switching in AEZs at lower altitudes that are characterized with relatively drier and hotter climate than those in higher altitudes (Hurni, 1998).

To summarize, the main steps involved in our method are:

I. The study first identifies the types of crops permanently adopted or dropped in the study area over the last 2 decades.
II. We disentangle the crop-switching decisions primarily driven by climate change based on subjective rating of farmers.

III. A logit model is employed to identify the determinants of adaption by crop switching. The dependent variable is whether or not a farmer has permanently switched crops because of climate change, i.e., a dummy variable.

3.3 Results

3.3.1 Household Characteristics and cropping pattern

The average age of the sampled household heads is 51. The majority of the respondents are male (84%). An average household owns 0.95 ha of land (S.D=0.47), and cultivates 0.98 ha (S.D=0.5) in the Meher season, the main growing season. The total land cultivated by the sampled households in the Meher season is 185 ha where 187 out of the 189 farmers grew at least one crop. For Belg season, only 17 ha is cultivated by 55 of the 189 farmers. The most commonly grown crop in Belg is barley followed by potato and onion, and Dega and Wurch are the main Belg producing AEZs.

The major crops grown in Meher season in Kolla and Weynadega based on cultivated area are teff and sorghum. Teff dominates in Weynadega, with about 60% of cultivated area, whereas sorghum is slightly more commonly grown in Kolla accounting about 42% of the cultivated land. Other important crops grown in the two AEZs include mung bean and maize. The Weynadega zone also hosts crops such as wheat, barley, fava bean and chickpea. The Dega and Wurch zones’ cultivation is highly dominated by barley, which covers about 57 and 78 percent of the land cultivated respectively. Almost all remaining land (19%) in Wurch zone is covered by potato production. Besides barley, the Dega zone, is covered with potato, wheat, fava bean and pea.

3.3.2 The process of crop-switching

Most farmers in all AEZs in Ankober district have switched crops at least once. The highest frequency of crop switching is in Kolla where 97.5% of the respondents have made at least one type of crop switching. In the remaining AEZs, the percentage is around 80%. Crop adoption took place on average 6.57 years (SD = 3.76) ago, and abandoning existing crops occurred about 7.24 years ago (SD=4.04). Crop adoption occurred relatively recently in Kolla AEZ with average year of 3.22 (SD=1.74) whereas it
has been occurring since on average 10.87 years (SD=2.05) in Dega. For crop abandonment, the notable inter AEZ difference is the fact that Weynadega areas are characterized with a little bit more recent adjustments, mean=5.40 (SD =3.03). Most farmers who adopted a new crop (67.57%) didn’t abandon any existing crop while the rest (32.43%) had to drop at least one existing crop. On the other hand, the large majority of farmers (89.9%) who dropped an old crop adopted at least one new crop.

### 3.3.3 Adopting new crops

The majority (95%) of farmers in Kolla zone started growing at least one new crop in the last 20 years. In the remaining AEZs, the percentage is relatively lower than Kolla and ranges between 72% and 78%. Few (13%) farmers adopted more than one crop.

In Kolla and Weynadega, the majority (>80%) of the adoptions involve mung bean (Figure 4). In Kolla, a good number (17%) of farmers also started growing onion. The other crops seldom adopted in the two zones are maize, sorghum, teff and tomato.

![Figure 4 Newly adopted crops by percentage of total number of adoptions in each AEZ (n stands for the number of switching decisions in each AEZ, it can be larger than sample size as some farmers switched crops more than once)](image)

In Dega and Wurch zones, the most frequently adopted crop is potato where it accounts 32% and 87.5% of the new adoptions in the two zones respectively. In Dega, the other crops adopted are beer-barley
(18%), cabbage (10.5%) and pea (10.5%). Other crops reported are apple, fava bean, wheat, onion, and garlic. In Wurch zone, cabbage (8%) and pea (4%) are adopted by few farmers.

### 3.3.4 Abandoning existing crops

Relatively high percentage of farmers in Kolla (65%) and Weynadega (30%) permanently abandoned growing existing crops at least once in the last 2 decades. In Dega and Wurch, however, only 7% (3 respondents) and 4 percent (1 respondent) of the respondents dropped old crops respectively. In Dega, abandoning pea and wheat were reported while in Wurch only one case of dropping potato was observed. To avoid ambiguity, we excluded the cases in these two zones from Figure 5. Maize is the major (57% of all cases) crop abandoned in Kolla followed by teff (30%). In Weynadega, fava bean accounts 36% of all crop-abandoning decisions followed by barley (21%), wheat (18%) and sorghum (11%).

![Figure 5 Abandoned crops by percentage of total number of similar cases in each AEZ (n stands for the number of switching decisions in each AEZ, it can be larger than sample size as some farmers switched crops more than once)](image)

### 3.3.5 Drivers of crop switching decisions

#### 3.3.5.1 Drivers of crop adoption

Price change is the most frequently (74-89%) cited primary reason for crop adoptions across all AEZs (Figure 6). Climate change is mentioned as the main driver for crop adoption only occasionally (less than 20% in all AEZs). Climate change is, however, rated as the second most important driver for the majority
of adoption decisions (70%). The examination of drivers for each of the newly adopted crops also reveals that in general the same set of drivers influence the adoption of the most commonly adopted crops i.e., mung bean in Kolla and Weynadega; onion in Kolla; potato in Dega and Wurch; and beer-barley in Dega.

![Figure 6 Drivers of crop adoption decisions across AEZs, hhld= household (n stands for the number of switching decisions in each AEZ, it can be larger than sample size as some farmers switched crops more than once)](image)

### 3.3.5.2 Drivers of abandoning crops

Climate change is by far the most important driver of abandoning crops in Kolla (90%) and Weynadega (79%); see Figure 7. Pest and disease, and price change are identified as the second most important drivers. Climate change is also the major driver for the commonly abandoned crops, i.e., maize and teff in Kolla; and fava bean, barley and wheat in Weynadega. Crop abandonments are rare in Dega and Wurch zones, hence we neglected the results for these two zones. Out of the total number of farmers (44) who dropped at least one crop due to climate change, 93% of them adopted mungbean where price is the main reason for the adjustment followed by climate change.

### 3.3.6 Determinants of crop switching

A logit model is fitted and marginal effects are estimated (Table 5). The dependent variable is a dummy variable defined as 1 if a farmer stopped growing an existing crop primarily due to climate change, and 0 otherwise. Since climate change is not strongly associated with adopting new crops, our analysis is confined to only crop abandonment. Out of the 189 households finally included in our analyses, 44 (23%) dropped at least one crop primarily due to climate change.
Figure 7 Drivers of crop abandonment decisions across AEZs, hhld= household (n stands for the number of switching decisions in each AEZ, it can be larger than sample size as some farmers switched crops more than once)

The logit model has a very good overall model fit shown by Likelihood ratio test (LR chi2 (10) = 71.82, p<0.01) (Table 5). Wald statistic also confirmed the same (chi2 (10)=31.51, p<0.01). Classification test showed that the model correctly specifies 82% of the time for a cutoff point of 0.5. Area Under ROC Curve (AUC) is 0.88, indicating a high predictive accuracy of the model. Variable Inflation Factor (VIF) values range between 1.13 and 1.45, which indicated the absence of any important multicollinearity problem. Land size and AEZ are the only variables that are significantly related to crop switching. Land size is positively related to crop switching. A one-hectare change on average is expected to increase the likelihood of adaptation by crop switching by 9.4%. The influence of AEZ is more pronounced where a shift to a higher altitude zone (i.e., from Kolla to Weynadega, for example) is associated with about 19% decline in the likelihood of adaptation by crop switching.
Table 5 Marginal effects of the logit model

<table>
<thead>
<tr>
<th>Determinants</th>
<th>Crop switching</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age of the household head in years</td>
<td>-0.001</td>
</tr>
<tr>
<td>Land owned in ha</td>
<td>0.094**</td>
</tr>
<tr>
<td>Family size</td>
<td>-0.001</td>
</tr>
<tr>
<td>Walking distance from market in hours</td>
<td>0.017</td>
</tr>
<tr>
<td>Level of education (dummy, 0 if illiterate and 1 otherwise)</td>
<td>-0.061</td>
</tr>
<tr>
<td>Access to extension services (dummy, 0 if without access, and 1 otherwise)</td>
<td>0.053</td>
</tr>
<tr>
<td>Access to credit (dummy, 0 if without access, and 1 otherwise)</td>
<td>0.034</td>
</tr>
<tr>
<td>Access to irrigation</td>
<td>-0.058</td>
</tr>
<tr>
<td>Number of relatives in village</td>
<td>0.001</td>
</tr>
<tr>
<td>AEZ (ordinal, 1 if Kolla, 2 if Weynadega, 3 Dega, and 4 Wurch)</td>
<td>-0.190***</td>
</tr>
</tbody>
</table>

*, ** and *** respectively indicate level of significance of 10%, 5% and 1%, and statistically significant values are written in bold.

### 3.4 Discussion

The main objective of the study is to disentangle specific group of switching decisions that are primarily motivated by climate change, and the socio-economic and environmental factors that influence them. The study shows that farmers in relatively drier and hotter AEZs are currently abandoning existing crops such as maize and fava bean as a response to climate change, but the adoption of new crops is primarily induced by price changes. The crop abandonment trend is inline with the predictions of ecological studies and crop-distribution modeling, which further validates our findings. The fact that abandonment rather than adoption is associated to climate change may also indicate the risk-averting behavior of smallholder farmers manifesting itself in the adaptation process to climate change. Most farmers who abandoned existing crops because of climate change adopted a cash crop (mung bean) primarily due to price increases for the crop because of new linkage to export market. The adoption of the cash crop is secondarily motivated by climate change, as it is evident in its agronomic qualities, and farmers’ subjective assessment. The most important determinants of crop switching as an adaptation strategy are land size and agroecology.
Our study revealed that considering crop switching as an adaptation strategy without narrowly defining it could be misleading. For the case study we examined, only crop abandoning is associated to climate change while the adoption of new crops is primarily motivated by price changes. This is a new finding which challenges the results of most previous studies that considered crop switching at aggregate level (e.g. Bryan et al., 2009; T.T. Deressa et al., 2009; Glwadys Aymone Gbetibouo, 2009; Maddison, 2007). The association of abandoning crops to climate change also suggests that farmers initially take more risk-averting measures to adapt to climate change.

Empirical evidence from studies on crop-distribution modeling and ecological change further validate our findings. In Kolla (lowland) and Weynadega (middle land) of the study area, a significant number of farmers shifted away from crops (teff, maize, fava bean, barley, and wheat) that are typically grown at higher altitudes, in relative terms to the particular AEZ considered (Hurni, 1998). This is what is expected as a warming climate shifts agroecologies towards drier classifications (Kala et al., 2012), or in upward direction for elevational range-shifts (Mekasha, Nigatu, Tesfaye, & Duncan, 2013). Furthermore, the result on the abandonment of maize is inline with the results of crop-distribution modeling by Rippke et al. (2016). According to this study, the suitable climate space for maize in sub-Saharan Africa is shrinking and 30 percent of the currently cultivated area may become unviable by the end of this century. And Ethiopia is one of the regions that is affected by this particular change (Rippke et al., 2016). The decline of land allocated to barley production, one of the abandoned crops, in Ethiopia has also been reported (Rashid et al., 2015). The fact that crop abandonment is rare in higher altitudes (Dega and Wurch) may be related to the positive influence of non-climatic drivers that offset the effect of climate change. For example, abandoning barley in higher altitudes may be delayed due to price increase in relation to flourishing beer factories in the vicinity of the study area, which is actually the case in our study area. This issue, however, needs further empirical investigation.

The importance of market dynamics in the adoption of the commonly adopted new crops in the study area i.e., mung bean and potato, is well supported. Mung bean is a cash crop that is in recent times enjoying high increase in price due to rise in export demand (Seyoum, 2014). Besides its market advantages, the crop possesses favorable characteristics of short growing period and suitability for semiarid climate (Beshah, 2015). Similarly, potato is one of the fastest expanding crops in the country owing to its nutritional advantage, increasing local demand and short growing season (Emana & Nigussie, 2011; Haverkort et al., 2012).
To sum up, farmers in Kolla (lowland) and Weynadega (middleland) switched away from crops such as maize and favabea primarily due to climate change, and a large majority of them have adopted mungbean for which price is the main driver followed by climate change. This demonstrates the importance of opportunities, in this case favorable price, in adapting to risks. The adoption of mungbean is an opportunity created due to export market linkage, yet its agronomic qualities makes it an ideal candidate to adapt in climate change. The fact that farmers rated climate change as the second important driver next to price supports this argument.

This study examined the determinants of adaptation by crop switching. Land size and AEZ are significantly correlated with adaptation by crop switching. Farmers with bigger land are found to be more likely to switch crops as a response to climate change. Larger land may allow experimentation with different crops that facilitates appropriate switching. The finding could also be associated with the general correlation of land size with wealth as it represents a major asset of a smallholder farmer. The importance of land size in farm-level adaptations has been shown by a number of studies in the past (Alauddin & Sarker, 2014; Nhachena & Hassan, 2007). The inverse relationship of adaptation by crop switching to AEZ (ordered altitude wise) is also inline with the findings of previous studies. It has been shown that farmers in drier and hotter climate zones are more likely to take adaptive measures (T. Deressa et al., 2009).

The interpretation of our results should, however, be made keeping some conditions in perspective. The first is the design of our sampling that selected a study area that shows variations in AEZs within a short distance. Such design is likely to include the borders of the climate spaces of various crops, which are the frontlines of shifts in crop mixes as the climate changes (Cho & McCarl, 2017). Hence, it is probable that this type of sampling design reveals more switching decisions than could have been otherwise. Moreover, our study area, Ankober district, located 40 km to the nearest asphalt road/major town, is by Ethiopia standard (Schmidt & Kedir, 2009) relatively close to a major urban center. The importance of market changes are, therefore, more likely to have a pronounced effect in the district. Finally, this study used a sample size of 190, which is big enough for the analysis we performed but can be considered small relative to several studies in the literature. The results should, therefore, be interpreted in light of this fact, and the research problem can highly benefit from future studies.

The major policy implication of our study is that adaptation through crop switching is better facilitated taking into account opportunities in the environment. The specific case of mung bean can serve as a classical example of how farmers can adapt using opportunities in their environment through adjustments
that are well tuned to a changing climate. Moreover, the risk-averting behavior of smallholder farmers in low-income countries (Hamal & Anderson, 1982; Yesuf & Bluffstone, 2009) could confine their adaptation responses to crop abandonment, at least initially. Besides, our findings revealed the strong correlation of the process of adaptation responses to agroecology, and implied the need for spatially cautious adaptation planning. Especially in mountainous countries such as Ethiopia where there is high agroecological diversity, a detailed spatial planning of adaptation could be vital.
Chapter 4
Factors affecting smallholder farmers’ adaptation to climate change through non-technological adjustments

Yibekal Abebe Tessema, Jonas Joerin, Anthony Patt

Abstract

Smallholder farmers often employ inputs and practices they are traditionally well acquainted with to adapt to climate change. These types of adjustments, henceforth referred to as non-technological, are not only more feasible in the resource-constrained situation of smallholder farmers but also have a potential to significantly reduce the negative impact of climate change. However, a systematic study of these types of adaptations isolating them from technological ones is still lacking. While technological adaptations can benefit from the extensive literature on the adoption of agricultural technologies, non-technological adaptations still need further examination as one distinct group of adjustments. We hypothesize that this group of adaptations strongly depend on farmers’ accumulated experience rather than financial resources and level of schooling. To test this hypothesis, we compared the determinants of changing planting date and changing crop type as non-technological adaptations, with the determinants of two technological adaptations: fertilizer use and rainwater harvesting. The investigation relied on a survey of 270 farm households in Semien Shewa Zone of Ethiopia. We used Wilcoxon Signed rank test and verified the importance of climate change in inducing the adjustments. A Multivariate probit model was then used to identify their determinants. Our hypothesis is supported by a positive relationship between farm experience and changing planting date, while fertilizer and rainwater harvesting showed a positive correlation with access to credit and level of schooling respectively. Our findings suggest that targeting non-technological farm-level adaptations through interventions focused on experience sharing can alone play an important role in reducing the impact of climate change in agriculture.

Key words: determinant; adaptation; non-technological; farm-level; climate change; multivariate-probit

4.1 Introduction

Climate change is expected to significantly reduce agricultural productivity especially in tropical and subtropical regions (Jones & Thornton, 2003; Knox et al., 2012; Rosenzweig & Parry, 1994; Zhang, Zhang, & Chen, 2017). For instance, the loss of yield for major crops that account for 80 percent of
production in Africa and South Asia may reach 8% by the middle of this century (Knox et al., 2012). Jones and Thornton (2003) estimate that a yield loss of 10% for maize alone in Africa and Latin America is equivalent to damage of $2 billion every year. In the absence of effective adaptation, such losses could translate into serious consequences for the welfare of a large number of people in the developing world (Nelson et al., 2009). IPCC (2014) defines adaptation as “the process of adjustment to actual or expected climate and its effects. In human systems, adaptation seeks to moderate or avoid harm or exploit beneficial opportunities”. Adjustment here, is interpreted as any change made by a household in managing resources to respond to climate change and other drivers.

Effective adjustment by farmers to changes in their environment including climate change may entail improved access to resources (Tol, Fankhauser, & Smith, 1998). According to the livelihood framework (Ellis, 2000; Scoones, 1998), farmers’ ability to achieve their livelihood goals depends on their vulnerability context, livelihood assets, and transformation of structures and processes. The vulnerability context represents the trends, shocks and seasonality faced by farmers. A farmer needs to adapt to these external factors by employing assets or resources at his/her disposal. As per the framework, livelihood assets are divided into five: human capital, social capital, physical capital, natural capital and financial capital. Improved access to these assets has been shown to influence the successful implementation of livelihood strategies (Babulo et al., 2008; Smith, Gordon, Meadows, & Zwick, 2001). However, the success of livelihood strategies also depends on access to institutions, infrastructural development, and policies, among others (De Haan & Zoomers, 2005; Ng’ang’a, Van Wijk, Rufino, & Giller, 2016). These are known as ‘structures and processes’ within the framework, and can be viewed as resources, which are not owned or controlled by individual farmers.

A growing number of papers, especially those dealing with smallholder farmers in the developing world, have produced different lists of farm-level adaptations along with their resource needs or socio-economic and institutional determinants (Alaeddin & Sarker, 2014; Bryan et al., 2009; T. Deressa et al., 2011; Maddison, 2007; Rahut & Ali, 2017; Shikuku et al., 2017). Farm-level adjustments, considered as adaptation responses by previous studies include: changing crop type, changing crop varieties, tree planting, soil and water conservation, changing planting date, fertilizer application and crop diversification (Below et al., 2012; Bradshaw, Dolan, & Smit; T. Deressa et al., 2011; Glwadys Aymone Gbetibouo, 2009; Maddison, 2007; Tesfaye & Seifu, 2016; Ubisi Nomcebo, Mafongoya Paramu, Kolanisi, & Jiri, 2017). The studies also identified heterogeneous factors that affect adaptation which include among others: level of education, income, availability of labor, access to credit, and access to
extension services (Adimassu & Kessler, 2016; Bryan et al., 2009; T. Deressa et al., 2009; Fosu-Mensah et al., 2010; Maddison, 2007; Ubisi Nomcebo et al., 2017).

However, earlier studies haven’t produced a distinctive set of determinants that differentiate the adaptation process from the process of agricultural technology adoption that has shaped agricultural policy for decades. The importance of factors such as access to credit, level of schooling, and income has already been well established through the vast literature on agricultural technology adoption (Burton et al., 1999; CIMMYT, 1993; Doss & Morris, 2000; Foster & Rosenzweig, 2010). This has made the results of many studies in the past redundant in terms of suggesting additional interventions specific to adaptation. Exceptions include a few studies that single out the importance of information (T. Deressa et al., 2009; Kichamu, Ziro, Palaniappan, & Ross, 2017), and farm experience (Arunrat, Wang, Pumijumnong, Sereenonchai, & Cai, 2017; Maddison, 2007).

The problem results from the fact that prior studies (Bryan et al., 2009; Maddison, 2007) failed to systematically address the difference in the resource needs of technological and non-technological (as we define it here) adaptation strategies. The former take place using relatively new inputs such as fertilizer and improved seeds, and their determinants are likely to be similar to adjustments studied in the agricultural technology adoption literature. The latter, however, could potentially have distinct resource needs as they employ inputs or technologies that a community has been familiar with over generations. Examples include: changing planting date, changing crop mix, and crop diversification. Despite differences between the two categories, studies in the past attempted to produce a single set of determinants under a general heading of ‘adaptation strategies to climate change’. For example, Maddison (2007) in their study on 11 African countries stated, “although experienced farmers are more likely to perceive climate change, it is educated farmers who are more likely to respond by making at least one adaptation”. Similarly, Falco, Veronesi, and Yesuf (2011) generalized that access to credit, access to extension and information are the key socio-economic factors that affect adaptation.

A separate examination of non-technological farm adjustments as one homogenous group can reveal a distinctive set of factors for farm-level adaptation to climate change. We hypothesize that these types of adjustments are relatively more influenced by farm experience than financial resources and level of schooling (see the following section for details). We tested our hypotheses based on a household survey in a study area in Semien Shewa Zone of Ethiopia. We examined the determinants of two non-technological adaptation strategies: changing planting date and changing crop type, along with two technological ones: rainwater harvesting and adoption of fertilizer. This study is one of the first to
consider non-technological adjustments as potentially distinct types of adaptation responses. Such approach ensures that non-technological adjustments are not overshadowed by technological adjustments, whose determinants point in the same direction agricultural development programs have already been following: more credit, more access to market, and more education. Non-technological adaptations such as changing crop type and changing planting date, while being a low-cost policy option, can also significantly reduce the impact of climate change (Costinot et al., 2016; Dharmarathna, Herath, & Weerakoon, 2014; P. Kurukulasuriya & R. Mendelsohn, 2008; Laux, Jäckel, Tingem, & Kunstmann, 2010; K. Waha et al., 2013).

4.2 Background

Farm adjustments that have been identified as adaptation responses to climate change are too diverse to allow the prescription of a single set of determinants. Despite this, several studies have attempted to do the same (Maddison, 2007; Oo, Huylbroeck, & Speelman, 2017). Such an approach could be linked to the legacy of the literature on agricultural technology adoption which usually treats technological adoptions as one group of adjustments that could be influenced by a closely related set of factors (Foster & Rosenzweig, 2010). In the adoption literature, the approach is valid because all the adjustments share the process of introducing a new input as a common denominator. When it comes to studying adaptation responses, however, this is not the case as adjustments could vary from a simple change in planting date, to adopting a new irrigation technology (Alemayehu & Bewket, 2017; Rahut & Ali, 2017; Yong, 2014).

One important way of categorizing farm adaptation responses with implications for their resource needs, is as transformative and incremental (Kates, Travis, & Wilbanks, 2012). The transformative ones are those that fundamentally change the characteristic of a farming system. An example could be shifting from mixed crop-livestock into agro-pastoral production system. Incremental adaptations, on the other hand, involve relatively marginal change, and are aimed at maintaining the existing state of the system (Wheeler, Zuo, & Bjornlund, 2013). In agriculture, such adaptations include changing planting date, changing crop type, adopting irrigation, etc. Transformative adaptation responses are distinguished by a larger scale of change, and can be considered distinct in terms of resource needs and outcome (Kates et al., 2012). The category of incremental, however, comprises of too diversified types of adjustments to allow any useful inference in the same way.

An alternative way of classifying adaptation options is as those in the intensive and extensive margin (Guo & Costello, 2009). Adjustments in the intensive margin involve continuous choice variables, where
only the magnitudes of inputs are altered (Guo & Costello, 2009). For example, reallocating land amongst existing crops. Adaptation at the extensive margin arises when discrete changes are made (Guo & Costello, 2009), an example being adopting a new crop species or variety. The strength of this taxonomy is its identification of adjustments in the intensive margin as one important categories of adaptation. Yet, adjustments in the extensive margin can still be quite heterogeneous. As a case in point, adopting a traditional crop that is well known to a particular community is likely to be different from the case of adopting a new improved crop variety. For the former, simple information provision can facilitate the process, while for the latter more resource intensive interventions such as training programs and creating links to markets may be required.

Here, we propose classifying adaptation strategies as those that primarily use existing technologies (non-technological) and those that adopt new technologies (technological). The former are farm adjustments that employ technologies or inputs that have been traditionally used by a community for generations. Examples include changing crop type, changing planting date, changing harvesting date, crop rotation and crop diversification. Such adjustments primarily depend on local knowledge that accumulated over generations, and heavily rely on resources that are widely available in the vicinities of the community. On the other hand, technological adaptations are similar to adjustments that have been studied in the agricultural technology adoption literature. At the extreme case, these types of adjustments lead to transformative adaptations. A rule of thumb to distinguish these adjustments can be to ask if they are still being systematically promoted or being diffused. Examples may include the adoption of fertilizer, irrigation technologies, pesticides, and farm machineries. While technological adaptations can benefit from the broad literature on determinants of technology adoption, non-technological adaptations can greatly benefit from further examination as a distinct group of adaptations. In this way it is ensured that all adjustments that are not technological are not overlooked.

Few studies have indicated the distinctiveness of ‘non-technological adjustments’. Shikuku et al. (2017) stated that the commonly observed adaptations of changing planting dates and changing crop species/varieties in their study area in East Africa share the same characteristics of being more associated with risk-reduction. The authors argued that their wide spread use could be due to their similarity in requiring ”little investment”. Kristjanson et al. (2012) using the same data set, also concluded, “many households are already adapting to changing circumstances, and their changes tend to be marginal rather than transformational in nature, with relatively little uptake of existing improved soil, water and land management practices”. Similarly, K. Waha et al. (2013) emphasized the importance of adjustments such as changing cropping pattern and sowing date which they named “low-tech adaptation options”. Non-
technological adaptations, despite the fact that they not have been systematically studied, have been identified as commonly employed adaptation strategies by smallholder farmers in different parts of the world (Alemayehu & Bewket, 2017; Laux et al., 2010; Oo et al., 2017).

We hypothesize that the key differences between non-technological and technological adaptations are on the importance of farm experience, level of schooling, financial resources and access to extension services. When adapting to climate change using old technologies, the experience of a farmer or his land-specific human capital is instrumental (Huffman, 2001). This is because experienced farmers have the advantage of being able to perceive climate change (Maddison, 2007), and having an accumulated knowledge of old technologies used in their community. In the case of technological adaptations, only the former mechanism works, as the technology adopted is relatively new. This is particularly true in situations where experience is the main source of information on climate change adaptation, which is likely to be the case in Ethiopia (Tessema et al., 2013).

Schooling is crucial especially for adjustments that are complex to learn (Foster & Rosenzweig, 2010). Non-technological adaptation responses are, therefore, less likely to be affected by level of schooling compared to technological adaptations, which introduce technologies relatively new to farmers. This is an especially good assumption if farmers with better schooling do not benefit from better access to information, which is one benefit of schooling, on non-technological adaptation (Foster & Rosenzweig, 2010; Tan, 2014). In this case, schooling acts as a substitute to experience. Finally, since traditionally used inputs can be cheaper and more readily available, the importance of financial resources in non-technological adaptation can be minimal. Thus, variables like farm income, and access to credit have relatively reduced influence on them.

Access to extension services is directly related to access to information on various issues including climate change and new technology, and, therefore, a positive relationship is expected for both non-technological and technological adjustments. However, since the former are relatively less resource-intensive, it is expected that access to extension services will have a more pronounced effect. In the specific context of our study area in Ethiopia, while the promotion of new technologies has been at the core of the public extension system (Abate et al., 2015; Abebe, Bijman, Pascucci, & Omta, 2013; Berhanu & Poulton, 2014), information on climate change adaptation has been reported to be very limited (T. Deressa et al., 2009; Tessema et al., 2013). Therefore, the importance of access to extension services is expected to be lower for non-technological adaptations compared to technological ones in the specific setting of the study area.
There is not expected to be a major difference between non-technological and technological adaptations in their relation to family size, land size, sex of the household head, access to market, and agroecological zone. Family and land sizes represent higher access to labor and land resources, and are likely to positively influence any adjustment. Changing planting date, however, is less likely to be associated with land size, as decision on planting date is hardly ever constrained by the availability of land. Female-headed households are known to be at a disadvantage in terms of accessing information, institutions and agricultural inputs in general due to social barriers (Wilson & Getnet, 2011). We, therefore, expect the sex of the household head to influence adjustments accordingly. Higher access to market can be correlated with higher access to information and better profitability of adjustments (Foster & Rosenzweig, 2010; Maddison, 2007). Therefore, market access is anticipated to invariably influence all types of adjustments. For changing planting date, however, the importance of market access is likely to be limited as it is not a type of adjustment that strongly affects cost, or type of output. The agroecological zone a farmer resides in is predicted to influence her/his adjustment decisions. Yet it is problematic to hypothesize on the nature of influence for each type of adjustment.

The main hypothesis of this study was supported by an assessment of 13 studies which considered farm-level adaptation (Table 6) concentrating on statistically significant ($\alpha =5\%$) results for key determinants of changing planting date, changing crop type, and irrigation as adaptation responses. The first two adjustments are investigated in this study as non-technological adaptations. Access to extension services and experience are the two most frequently identified variables that positively affect changing planting date. For changing crop type, access to extension services and agroecological zone are the most influential variables. Adoption of irrigation (included in the assessment as a technological adjustments) is usually affected by income and access to credit.
Table 6 Summary of key determinants identified in the literature for changing planting date, changing crop type and adoption of irrigation (negative relationships are preceded by ‘–v’)

<table>
<thead>
<tr>
<th>Determinants</th>
<th>Changing planting date</th>
<th>Changing crop type</th>
<th>Irrigation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social capital/memberships</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Family size/labor</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
4.3 Methods

The main objective of this study is to identify the socio-economic determinants of non-technological farm-level adaptation responses that differentiate them from technological adaptations. To this end;

1. We first identified two non-technological and two technological farm-level adaptations, and examined the degree of association of each of them to climate change based on the subjective rating of farmers.

2. We analyzed the correlation between farmers’ decision to adopt the selected adaptation strategies and their socio-economic characteristics. We then interpreted the results for the non-technological in comparison to the technological ones. Whether or not a farmer adopted the adjustments was the basis for defining the dependent variables i.e., irrespective of their relation to climate change. This is because the effect of socio-economic determinants should be inferred from whether a farmer managed to adopt a particular adjustments or not, irrespective of its association to drivers. As described above in the first step, however, we first showed the importance of climate change as a driver for the selected adjustments.

Our study is based on a rural household survey in the Semien Shewa Zone of Ethiopia, which is situated in the central highlands of the country (Figure 3). Ankober Woreda (district) was purposively selected as it is characterized by typical altitudinal ranges and agricultural production systems in the Zone and in Ethiopia (CSA, 2013; Ege, 2005; Hurni, 1998). The district encompasses four major agroecological zones of the country. These are Kolla (lowland, altitude 500-1500 m a.s.l.), Weynadega (middle land, 1500-2300 m a.s.l.), Dega (highland, 2300-3200 m a.s.l.), and Wurch (frosty zone, above 3200 m a.s.l.) (Hurni, 1998). Three Kebeles (the lowest administrative unit) were purposively selected; one from Kolla, one from Weynadega, and one from Dega. We allocated a total sample size of 240 among these Kebeles approximately proportional to the share of the three agroecological zones in Semien Shewa Zone. Therefore, 50 percent is allocated to Kolla (lowland), 25 % to Dega (middle land) and the remaining 25% to Kolla. For the Wurch (forsty zone), since its share is very low in the study area we used a sample size of 30, the minimum size recommended according to the central limit theorem. For this purpose, we used only a few villages falling in the Wurch Zones in our sampled Kebele for Dega. Hence, a total sample size of 270 was used for our study. Households in the sampled Kebeles were selected using systematic random sampling and data was collected using structured interviews.
We examined the determinants of two non-technological and two technological farm-level adaptation responses to climate change. We considered changing crop type and changing planting date as non-technological adjustments to climate change. Changing crop type occurs when a farmer adopts a new crop or drops an existing one, or does both at the same time. Changing planting date is a permanent change in the sowing time of crops to adapt to changes in climatic parameters. Changing planting date, as the name implies, is carried out using available crops and does not necessitate new technologies. Changing crop type in the study area is assumed to involve primarily crops already in use in the district or in the region. This assumption is supported by key informant interviews that included development agents in the study area. We also examined two technological farm-level adaptations to allow the interpretation of our results in relation to technological adaptations. These are chemical fertilizer application and rainwater harvesting. Rainwater harvesting technologies refer to the small-scale on-farm water harvesting ponds being promoted by the Ethiopian government. These adjustments were selected as they are relatively new technologies in Ethiopia which are still in the process of diffusion (Awulachew et al., 2005; Spielman, Mekonnen, & Alemu, 2012), and therefore represent technological adaptations. To distinguish the four adjustments from coping strategies, farmers were specifically asked to mention only permanent adjustments they had made over the last 10 years.

To determine the relative importance of climate change amongst other drivers in terms of influencing adoption decisions, farmers were asked to rate (on a scale of 1-3) climate change along with other drivers for each of the four adjustments considered in our study. The other drivers were: access to agricultural extension services, land degradation, crop pests and diseases, and trends in demand or price of commodities. These drivers were selected due to their well-established significance as trends and shocks that drive livelihood strategies in Ethiopia (Eshete et al., 2015; PPSE, 2008; Shimeles & Delelegn, 2013; World Bank, 2007). To determine if there are significant differences in farmers’ rating of drivers for each farm-adjustment, the Wilcoxon Signed rank test was used. We tested the null hypothesis that farmers’ rating of climate change is the same as their rating of other drivers. The test was performed for each of the four adjustments (Table 3).

A multivariate probit (MVP) model, following Greene (2003), was applied where the adoption choice of farmers (1 if adopted, 0 otherwise) was used as the dependent variable together with 10 explanatory variables (Table 7). The hypothesized relations are based on the preceding literature review. MVP is suitable for our study as it uses a multivariate distribution, which accounts for the substitutability or complementarity of choices, in our case farm-adjustments (Lin et al., 2005; Nhemachena & Hassan, 2007). This model has been successfully used in the climate adaptation literature (Nhemachena & Hassan,
2007) and in research areas with similar multi-choice situations (e.g. Choo & Mokhtarian, 2007). The number of draws used for our study is 500 which is a safe choice for our number of equations (Cappelari & Jenkins, 2003). To check for multicollinearity problem, VIF was calculated.

Table 7 Description of explanatory variables and hypothesized relations

<table>
<thead>
<tr>
<th>Independent variables</th>
<th>Description</th>
<th>Hypothesized signs*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Farm experience of the household head in years</td>
<td>Continuous</td>
<td>Non-technical: + 0</td>
</tr>
<tr>
<td>Land owned in ha</td>
<td>Continuous</td>
<td>Non-technical: + +</td>
</tr>
<tr>
<td>Sex of the household head</td>
<td>1 if female, 0 otherwise</td>
<td>No hypothesis</td>
</tr>
<tr>
<td>Family size</td>
<td>Continuous</td>
<td>No hypothesis</td>
</tr>
<tr>
<td>Walking distance from market in hours</td>
<td>Continuous</td>
<td>No hypothesis</td>
</tr>
<tr>
<td>Level of schooling</td>
<td>Dummy, takes the value of zero if illiterate and one otherwise</td>
<td>0 +</td>
</tr>
<tr>
<td>Access to extension service</td>
<td>Dummy, takes the value of zero if without access and one otherwise</td>
<td>0 +</td>
</tr>
<tr>
<td>Farm income (excludes off-farm income)</td>
<td>Continuous</td>
<td>0 +</td>
</tr>
<tr>
<td>Access to credit</td>
<td>Dummy, takes the value of 0 if without access and one otherwise</td>
<td>0 +</td>
</tr>
<tr>
<td>Agroecological zone</td>
<td>Ordinal based on altitude: 0=if Kolla, 1=Waynadega, 2=Dega, 3=Wurch</td>
<td>No hypothesis</td>
</tr>
</tbody>
</table>

*Plus and minus signs respectively indicate positive and negative correlation. Zero represents the absence (or a slight positive if any) correlation

4.4 Results

In this section, the degree of association of the selected farm-adjustments to climate change, and the results of the MVP model are presented.

4.4.1 The relative importance of climate change as a driver for the selected farm-level adaptations

Climate change appears to be a major driver for the three of the adjustments, with the exception of fertilizer use (Table 8). Climate change was rated highly as a driver for changing planting date, changing
crop type, and rainwater harvesting. For changing crop type and rainwater harvesting, however, climate change was not rated significantly high in comparison to trends in demand or price and access to agricultural extension services. For fertilizer application, our result revealed that non-climatic factors are more important. Access to agricultural extension services and trends in demand seemed to drive the adoption of fertilizer use in the study area. Climate change was, however, rated higher than crop pests and diseases in determining whether fertilizer is used.

Table 8 Wilcoxon signed-ranks test (Ho: Rating of climate change = rating for another driver)

<table>
<thead>
<tr>
<th>Farm-adjustment</th>
<th>Z-values, (Ho: Rating of climate change = rating for each driver below)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Changing crop type</td>
<td>Agricultural extension services 2.339**, Land degradation 10.557***, Crop diseases and pests 7.231***, Trends in demand or price -0.734</td>
</tr>
<tr>
<td>Changing planting date</td>
<td>10.312***, 11.790***, 11.10***, 10.811***</td>
</tr>
<tr>
<td>Use of fertilizer</td>
<td>-11.304***, -3.397***, 3.319***, -5.891***</td>
</tr>
<tr>
<td>Rainwater harvesting</td>
<td>0.728, 4.014***, 4.490***, 3.734***</td>
</tr>
</tbody>
</table>

*, ** and *** respectively indicate level of significance of 10%, 5% and 1%, and values are in bold only where climate change is rated higher

4.4.2 Determinants of non-technological farm-level adaptations

The MVP model was run with four dependent variables, and ten explanatory variables (Table 9). The prediction power of the model is high (Wald chi2(40) = 129.09, and Prob > chi2 = 0.0001). VIF values are all below the threshold level of 10 that verified the absence of a major multicollinearity problem. Approximately 89 % of respondents adopted fertilizer and switched crops, while changing planting date took place in 87% of the farms. Contrary to these figures, rainwater harvesting was adopted only by about 20 % of the respondents.

The results of the model are generally in the direction of our initial expectations. This is particularly true for three of the four key explanatory variables we expected to show the distinguishing features of non-technological adjustments: farm experience, level of schooling, and access to credit. Farm income, one of the key variables, however, did not show any statistically significant relationship with any of the adjustments. For the first three key variables, the hypothesized differences between non-technological and
technological adjustments are supported by a statistically significant relationship for one of the adaptations.

Table 9 Results of the MVP model

<table>
<thead>
<tr>
<th>Explanatory variables</th>
<th>Non-technological adjustments to climate change</th>
<th>Technological adjustments to climate change</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Changing crop type</td>
<td>Changing planting date</td>
</tr>
<tr>
<td>Farm experience of the household head in years</td>
<td>-0.003</td>
<td><strong>0.017</strong></td>
</tr>
<tr>
<td>Land owned in ha</td>
<td><strong>0.483</strong></td>
<td>0.021</td>
</tr>
<tr>
<td>Sex</td>
<td>0.340</td>
<td>-0.295</td>
</tr>
<tr>
<td>Family size</td>
<td>0.087</td>
<td>0.021</td>
</tr>
<tr>
<td>Walking distance from market in hours</td>
<td>-<strong>0.535</strong>*</td>
<td>-0.155</td>
</tr>
<tr>
<td>Level of schooling</td>
<td>0.127</td>
<td>0.047</td>
</tr>
<tr>
<td>Access to extension service</td>
<td>-0.207</td>
<td>-0.322</td>
</tr>
<tr>
<td>Farm income (excludes off-farm income)</td>
<td>0.00002</td>
<td>1.23 e-06</td>
</tr>
<tr>
<td>Access to credit</td>
<td>0.176</td>
<td><strong>0.421</strong></td>
</tr>
<tr>
<td>Agroecological zone</td>
<td><strong>0.302</strong>*</td>
<td>0.171</td>
</tr>
</tbody>
</table>

*, ** and *** respectively indicate level of significance of 10%, 5% and 1%, and statistically significant values are written in bold. The shaded indicate the rows we expect differences between the two categories of adaptations.

Our hypothesis that farm experience has more influence on non-technological adjustments than level of schooling and access to extension services is supported by our analysis. Farm experience was positively correlated with changing planting date while the result is insignificant for changing crop type. None of the coefficients for the technological adjustments are significant for this variable. On the other hand, level of schooling has a statistically significant correlation with one of the technological adaptations, rainwater harvesting. On the premise that the public extension system in Ethiopia does not impart much climate
change related information, we expected access to extension would show a relatively stronger relationship for the technological adjustments than the non-technological ones. In partial agreement with this, adoption of fertilizer is significantly associated with access to extension services.

In line with our hypotheses, socio-economic factors representing access to financial resources showed a stronger relationship to technological adjustments. Access to credit is significantly related to both technological adjustments. Contrary to our expectation, the direction of relationship is negative for rainwater harvesting. Changing planting date is also marginally related (p<10%) to farmers’ access to credit. It is important to note however, that our hypotheses propose a weak relationship between non-technological adaptations and access to financial resources, rather than a complete absence of any link. Despite our expectations, farm income is not significantly correlated with any of the adjustments.

The explanatory variables we expected to have no differential influence on non-technological adjustments manifested somewhat contrasting results. Gender of the household head, walking distance from market and agroecological zone did not show any pronounced variance in their relation to the two groups of adjustments. Land size, and family size, however, showed results contrary to our expectations. Family size is associated only with fertilizer application. Land size, on the other hand, is only strongly associated with rainwater harvesting (a technological adjustment). Land size, showed a slight (p< 10%) correlation with changing crop type. The unexpected relationships observed for family and land size pose a slight challenge to our positive results on the key variables. This result can be interpreted as the probability of accepting a false hypothesis, or type I error.

4.5 Discussion

The aim of our study is to investigate if non-technological adjustments to climate change require a distinctive set of resources compared to technological ones. Our results support that this is actually the case. Non-technological adaptations are found to be more dependent on farm-experience, and less on financial resources (access to credit) and level of schooling. Access to extension services is also shown to be less important for non-technological farm-level adaptations, possibly due to a limited amount of climate information services in the extension system of Ethiopia. Two farm-level adaptations are considered from both technological and non-technological adaptation responses. Changing crop type and changing planting date represented non-technological adjustments, whereas fertilizer application and rainwater harvesting were considered as technological. All the farm-level adaptations are initially shown to have some degree of association to climate change based on farmers’ subjective rating of drivers. Our
findings are supported by a statistically significant relationship found in the direction hypothesized by at least one of the farm-level adaptations.

This study is one of the first to separately examine non-technological farm-level adaptation responses as a distinct group of adaptations. However, it is possible to compare results with those of previous studies, which provided detailed results on determinants of each type of adaptation response they included. The summary of results for 13 previous studies (Table 6) support our findings, with the exception of access to extension services. In situations where extension systems deliver climate relevant information, their effect should theoretically be pronounced for non-technological adjustments. However, in the case of Ethiopia, the results are justifiable, as the extension system has been reported not to include climate related information (T. Deressa et al., 2009; Tessema et al., 2013). Furthermore, evidence in the agricultural technology adoption literature support our results on farm-experience and schooling. Huffman (2001), for example, stated that in a relatively static environment (including technological environment), accumulated farm experience is more valuable than schooling.

Nevertheless, there are some inconsistencies between our original hypothesis and our results. The negative relationship between access to credit and rainwater harvesting is unexpected. It could be explained by the availability of alternative water technology which is favored if financial resources are available. Land and family size also showed an asymmetrical relationship and appear to influence technological adjustments more than non-technological ones. For changing planting date, we specifically expected no relationship with land size, which reduces the probability of showing a positive relationship for the non-technological side. In addition, it should be noted that a discrepancy for a no-relationship hypotheses is more likely to happen than a discrepancy for the type of relationship we expected for the key variables. Therefore, the results for land and family size should be considered in light of this fact.

Our study is one of the first, if not the first, to systematically investigate the difference between technological and non-technological adaptations, yet it included only two adjustments to represent each of these two categories. We also relied on a significant result for only one adaptation response each time to support our hypotheses. Further research on non-technological adaptations is therefore needed. Furthermore, it should be recognized that each type of farm-level adaptation response is unique in terms of its determinants. The goal of this study was to show general tendencies in terms of the socio-economic factors affecting non-technological adaptations.
Our findings suggest that targeting non-technological farm-level adaptations through interventions focused on experience sharing and information dissemination alone, can play an important role in reducing the impact of climate change in agriculture. Patt, Suarez, and Gwata (2005) had closely related results where they showed the strong effect of participatory workshops and climate information on non-technological adaptations. Based on a study in Zimbabwe, they demonstrated that information on seasonal forecasts, specifically when communicated in workshops, significantly improved farmers’ yields particularly when their adjustments were non-technological. The lesser dependence of these types of adjustments on financial resources and level of schooling indicate that low-investment interventions are possible. This is an advantage in the context of developing countries where limited financial resources and education level often characterize smallholder farmers. Adaptation policies should ensure that the potential of non-technological adaptations is fully realized as they can represent cheap and feasible options to reduce the negative impacts of climate change. Furthermore, our findings underscore the need for a typology of farm-level adaptations that recognizes the distinctiveness of non-technological adaptation responses to climate change. This will ensure that this category of adaptations is not overlooked in development programs, which currently focus on the dissemination of new technologies.
Chapter 5
Synthesis and Policy Implications

Farmers have been adjusting to a multitude of exogenous changes in their environment, both negative and positive. Correspondingly, agricultural policies have been engaged on ensuring that farmers are exploiting opportunities such as technological innovations while reducing the damage from threats such as soil erosion and pest outbreak. In developing countries, these policies have taken the central place in poverty alleviation and economic development. There is now a new major change that farmers need to adapt to and, and once again agricultural policies need to facilitate, climate change.

This thesis is aimed at contributing to an overarching research question of what new interventions are required in agriculture to adapt to climate change. Just like many studies in the past, I attempted to answer this question by examining the process of farmers adaptation to climate change and its resource needs or determinants. However, this thesis made key improvements in the methodology and approach of previous studies, which had serious flaws in identifying farm-level adaptations and their determinants. Based on a study area in Ethiopia, the thesis produced key insights that could be significant additions to the existing literature and ultimately to policy-making.

In the second chapter, by putting non-climatic drivers in perspective and by applying a new methodological approach that reduces response biases, I attempted to reveal the relative importance of climate change in inducing farm adjustments. In the study area, I found three adjustments that are primarily motivated by climate change: changing planting date, crop switching, and crop diversification. A closer look into crop switching, in the third chapter, also validated this finding. Crop switching, specifically the abandonment of old crops, was shown to be primarily induced by climate change. The fact that crop abandonment is particularly linked to climate change may indicate that farmers may prefer risk-averting measures at least initially. This may also mean that new crop adoptions that are needed for adaptation are not taking place at the required pace.

A common characteristic of the three adjustments is the fact that they do not necessitate new inputs or technologies. One may like to use the term incremental to these types of adjustments. However, incremental adjustments, which are the opposite of transformational, can also include adjustments that employ new technologies. Hence, in this study I adopted a new term non-technological adaptations for these types of adjustments, in contrast to technological adaptations. The fourth chapter showed that non-technological adaptations are less resource intensive and are particularly correlated to farm experience.
This characteristic of non-technological adaptations makes them excellent adaptation options under the resource-constrained context of smallholder farmers in developing countries.

The findings of the thesis shed important light to the overarching question it started with: what new interventions are required in agriculture to adapt to climate change. Two of the three adjustments singled out by the thesis as farm-level adaptation strategies can be considered new to the agricultural policy arena. Changing planting date and crop switching (involving old crops), also referred to as changing crop type, can be considered new types of adjustments whose importance has grown only in recent times due to climate change. Farmers used to have traditionally fixed dates for sowing, which have become ineffective in recent times (Chmielewski, Müller, & Bruns, 2004; K. Waha et al., 2013). The abandonment of traditionally cultivated crops like maize and fava bean is also probably a new phenomenon as it is inline with expected ecological change in climate change. Furthermore, these two types of adjustment are likely to require new interventions, which should focus on experience sharing or dissemination of information, as they are non-technological adaptations. Such experience-focused intervention can by itself be considered a new addition to the ongoing agricultural development process, which is often concentrated on making farmers familiar with new technologies and practices. For crop diversification, however, farmers have been employing it for various types of market and production risks, and hence it is hardly an adjustment that may benefit from further interventions.

The broader implication of my findings is that non-technological adaptations need to be the primary focus in adaptation planning. Although they may appear routine, these types of adaptations can substantially reduce the damage from climate change (Pradeep Kurukulasuriya & Robert Mendelsohn, 2008; Waongo, Laux, & Kunstmann, 2015). Technological change is already the number one priority in agriculture and in general in economic development across the world. Institutions and policies have been engaged on availing improved seeds, fertilizers and other new technologies. Furthermore, it is unlikely that we can suggest unique technological adoptions in relation to climate change. This can be the case only if climate change creates unique agro-ecological conditions that have not existed in the past. In which case, we need to think of new crop varieties or irrigation systems that are tuned to these new conditions. However, there has not been any evidence that climate change has caused, or will cause in the future, new types of ecological or farming conditions. Scientific evidence so far is only suggesting that climate change is contracting or expanding existing agro-ecological zones (Cho & McCarl, 2017; Rippke et al., 2016). A farmer, for example, may need to shift from wheat to sorghum because of increased moisture stress due to climate change. But this does not imply that new technologies are required. Sorghum production is most probably practiced in the vicinities of the farmer along with the associated improved technologies.
One way of looking at the process of non-technological adaptations is as the reallocation of resources at community level. A community at a particular geographical location is endowed with various inputs or technologies that are suitable to different agro-ecological conditions. In our study district, for example, there are four agro-ecologies with at least four types of farming types. As the climate changes, places falling in moist agro-ecologies may shift to drier classifications entailing farm adjustments. However, these adjustments depend on inputs and practices already familiar to the community. That is why farm experience may have crucial value in facilitating non-technological adaptations as experienced farmers are likely to have broad-based knowledge about their community to efficiently adapt using its endowments of resources and knowledge.

At a general level, I would argue that adaptation to climate change is essentially facilitating the reallocation of resources already available in a community or society, which can be considerably facilitated by experience sharing or information dissemination. Interventions may take a form of organizing group discussion sessions involving farmers from neighboring agro-ecological zones with the aim of improving farmers awareness and knowledge on farming practices widely applied in their community or adjacent communities. When a new change occurs in ones surrounding, it also makes sense first to ensure that a community’s endowments are fully engaged in tackling the new problem. Since climate change is a gradual process shifting the borders of agro-ecologies, it is also likely that the solution is found next-door. Besides, interventions should target enhancing the awareness of farmers about the expected changes in agriculture due to climate change. It has been established that people’s expectation of climate change is a critical factor whether they take adaptive actions or not (Weber, 1997).

There is, however, a foreseeable risk that the dominant discourse on adaptation that emphasizes on technology transfer (Biagini, Kuhl, Gallagher, & Ortiz, 2014; Clements, Haggar, Quezada, & Torres, 2011) could overshadow non-technological adaptations which are the most feasible yet very effective adaptation options. For example, Biagini et al. (2014) who assessed 66 adaptation projects managed by the Global Environment Facility (GEF), large number of which are in agriculture, showed that most projects (74 %) have a technological focus. Even if the importance of new technologies is unquestionable, for some economic sectors like agriculture, the main role in adaptation could be played by non-technological adaptations. Overlooking these adaptations could be a big loss of opportunity as they have the potential to reduce the damage from climate change by over 60 percent (Costinot et al., 2016; Pradeep Kurukulasuriya & Robert Mendelsohn, 2008).
Moving to Ethiopia as a specific case, my arguments support some modifications to existing policies. There are two key strategic plans that address adaptation in agriculture: Ethiopia’s Climate Resilient Green Strategy (CRGS), and the National Adaptation plan (NAP-ETH) (CRGS, 2011; NAP-ETH, 2017). CRGS has developed a detailed strategy on the sectors of agriculture and forestry. The strategy identified 41 major adaptation options, out of which 15 are prioritized. Crop switching and new varieties are one of the 15 options prioritized by the strategic plan. CRGS, however, does not explicitly state the need for monitoring the change in the suitable spaces of crops and the best strategies to address this change except for coffee. Besides, the importance of making appropriate changing planting dates is not sufficiently emphasized by the strategy. CRGS should recognize non-technological adaptations as distinct types of adaptations that offer a unique opportunity to reduce the damage from climate change, and devise mechanisms to systematically facilitate them.

NAP-ETH falls under the CRGS and was recently, in 2017, announced as a national adaptation plan for the next 15 years. Despite the prioritization of crop switching in the CRGS, the NAP-ETH did not include the option in its 18 adaptation options shortlisted for action. The plan focuses on measures that improve agricultural productivity like introducing improved crop varieties. Non-technological adaptations are already taking place as also indicated by this thesis. Hence, prioritizing them as an important adaptation option to be monitored and addressed starting from the present is vital. This would ensure that we can fully exploit the opportunity presented by these types of adaptations as they are low-cost yet very effective adaptation strategies. NAP-ETH highlighted the importance of mainstreaming endogenous or traditional adaptation practices. However, the plan doesn’t adequately clarify which adaptation strategies are considered as endogenous adaptation practices.

Incorporating non-technological adaptations in adaptation planning requires at the first place recognizing them as distinct types of adaptations in the adaptation literature. A major step would be to include a typology that defines them in the IPCC report. The commonly used typology at present that classifies adaptations as incremental and transformational as well explained in this thesis is not adequate to capture the heterogeneity of adaptation strategies. Moreover, the term adaptation should also be defined in a way that puts non-climatic drivers in perspective. An adjustment is made by a farmer as a response to multiple drivers simultaneously occurring in his/her environment. Therefore, the definition of adaptation should clarify when we could call a particular adjustment an adaptation strategy. As we argued in this thesis an adjustment should be identified as an adaptation strategy when only it has a relatively strong linkage to climate change compared to other drivers. Such an approach allows adaptation planning to separately consider adjustments that call for new interventions from those that only need mainstreaming. Such
clarification in definition is also likely to bring non-technological adaptations to surface as distinct types of adjustments.

Furthermore, I found that non-climatic drivers like market dynamics induce the majority of farm adjustments, and hence mainstreaming climate change in policies targeting these drivers is very crucial. An interesting case in this regard is given by the adoption of mung bean in our study area. The rise in export demand for mung bean is the main driver for its adoption but the agronomic qualities of the crop such as drought tolerance have made it an excellent candidate for adaptation. The case provides an excellent example of how adaptation to climate change can be mainstreamed in policies that are primarily driven by opportunities. NAP-ETH and CRGS need to ensure that adaptation is mainstreamed by giving due attention to the synergies and tradeoffs between adjustments induced by different drivers. Such approach is, however, not adequately emphasized by the strategic plans. This is also an area that lacks empirical evidence and could highly benefit from further research.

Finally, the impact of climate change in agriculture is highly location-specific and adaptation needs to be spatially planned. Farm adjustments decisions, including those primarily motivated by climate change, were shown in this study to be strongly correlated to agro-ecological conditions. Besides, adjustments such as crop switching will probably start at the edge of agro-ecological zones where the adjustment gradually diffuses following the shift of ecological borders. Hence, detailed spatial planning may be particularly required for these types of adjustments. The spatial consideration in NAP-ETH and CRGS is, however, confined to identifying high climate risks areas to address particularly vulnerable communities. Spatial planning, however, should not be confined to this and should also include incorporating mechanism to monitor the shifts of agro-ecological zones.
Acknowledgements

First and foremost, I would like to thank God the Almighty for His love and blessing throughout my life.

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https://http://www.nature.com/articles/nclimate3007 - supplementary-information


Land Degradation and Improvement – A Global Assessment for Sustainable Development (pp. 117-165). Cham: Springer International Publishing.


http://www.nature.com/nclimate/journal/v6/n6/abs/nclimate2947.html - supplementary-information


Appendix
Interview schedules

Survey I

Rural Household Survey
Interview Schedule

Introductory Statement:
“This survey is carried out to study farm-level adaptations to climate change in Ethiopia. The data collected will be used only for research purposes and any information provided by respondents will not be transferred to any third party in any form. Thank you for your kind cooperation.”

Household ID ______________________
Woreda ______________ Kebele ____________ Village (Got) ____________
Date of Interview: ________________________________
Interviewer: ______________________________________

Checked by ______________________ Date ______________
Data entry by ______________________ Date ______________
**Part I**  
**General Information**

**Household head**

<table>
<thead>
<tr>
<th>Description</th>
<th>Details</th>
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</thead>
<tbody>
<tr>
<td>Sex</td>
<td></td>
</tr>
<tr>
<td>Educational level1</td>
<td></td>
</tr>
<tr>
<td>Main occupation2</td>
<td></td>
</tr>
<tr>
<td>Religion</td>
<td></td>
</tr>
<tr>
<td>Age</td>
<td></td>
</tr>
<tr>
<td>Marital status (married, single)</td>
<td></td>
</tr>
<tr>
<td>Secondary occupation2</td>
<td></td>
</tr>
<tr>
<td>Land owned in hectares</td>
<td></td>
</tr>
</tbody>
</table>

1 *Educational level*:  
- a) illiterate  
- b) able to read and write  
- c) elementary  
- d) high school  
- e) college/university

2 *Occupation*:  
- a) mixed farming  
- b) animal production  
- c) crop production  
- d) house wife  
- e) daily labourer  
- f) dependent  
- g) civil servant  
- h) student  
- i) others, please specify

**Family members**

Please include household members who permanently live in the household

<table>
<thead>
<tr>
<th>No.</th>
<th>Sex</th>
<th>Age</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
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<td></td>
<td>Female</td>
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<td>3.</td>
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<td>7.</td>
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<td>8.</td>
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</table>
Part II
Institutions and resources

1. How many years of farming experience do you have? ______________

2. How many relatives do you have in your village (‘Got’)? ____________

3. Do you have access to irrigation water?  a) Yes     b) No

4. Are you a member in a cooperative?  a) Yes     b) No

5. If your answer for the preceding question is yes, please give the name of the cooperative and its main activities? ____________________________________________________

6. Have you taken any credit in the last 5 years?  a) Yes     b) No

7. If your answer for the preceding question is yes, what is your source of credit?
   a) Microfinance institutions b) Bank c) Local money lender d) Relatives and friends e) Cooperatives f) Others (please specify) ________________________________

8. Do you have access to extension services?  a) Yes     b) No

9. If your answer is yes for the preceding question, how often do you make contacts with extension agents in a year)? __________

10. How long do you have to walk to the nearest output market? ________

11. How long do you have to walk to the nearest input market? _________

12. Which one of the following media do you use?
   a) radio b) TV c) newspaper d) Others (please specify) _______________
Part III
Changes

1. What are the three major adjustments you made on the way you farm in the last 10 years?
   (Please rank in order of importance)
   ________________________________________________________________
   ________________________________________________________________
   ________________________________________________________________

2. What are the major causes or drivers for the above three and other similar adjustments?
   (Please use the Likert scale below)
   1) Strongly agree 2) Somewhat agree 3) Neither agree or disagree 4) Somewhat disagree 5) Strongly disagree

<table>
<thead>
<tr>
<th>Change in input prices and supply</th>
<th>Extension services</th>
<th>New infrastructure (road, telecom, etc.)</th>
<th>Land degradation (deforestation, soil erosion, pollution etc.)</th>
<th>Change in output demand or price</th>
<th>Climate Change</th>
<th>Natural hazards (pest, disease etc.)</th>
<th>Intra household changes (family size, income, education, etc.)</th>
<th>Others (specify)</th>
</tr>
</thead>
<tbody>
<tr>
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</table>
Part IV
Farm-adjustments and their drivers

Please use the scale below to rate the importance of drivers in inducing farm adjustments over the last 10 years.

1) High  2) Medium  3) Low

<table>
<thead>
<tr>
<th>Adjustments</th>
<th>Yes/No</th>
<th>Extension services (knowledge, technology, skill etc.)</th>
<th>Land degradation (deforestation, soil erosion, pollution)</th>
<th>Climate Change</th>
<th>Natural hazards (pest, disease, etc.)</th>
<th>Demand and price changes in general</th>
<th>Others (specify)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Soil and water conservation</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Crop diversification</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Planting trees</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water harvesting</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Changing planting date</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Change crop variety</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Change crop type</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Off-farm work</td>
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<td></td>
<td></td>
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<tr>
<td>Chemical fertilizer</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Irrigation</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Others (specify)*</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

* If there are adjustments mentioned in part III and not listed here please include them.
Part V
Perception and Adaptation to Climate Change*

1. Have you perceived permanent changes in average temperature over the last 20 years? (Please explain)

(If the respondent finds the above question difficult to understand, please rephrase the question as: have you perceived permanent changes in the frequency of hot days in the last 20 years?
Please mark x if this question is used)

______________________________________________________________________________
______________________________________________________________________________

2. Have you perceived permanent changes in average rainfall over the last 20 years? (Please explain)

(If the respondent finds the above question difficult to understand, please rephrase the question as: have you perceived permanent changes in the frequency of rainy days in the last 20 years?
Please mark x if this question is used)

______________________________________________________________________________
______________________________________________________________________________

3. Have you perceived permanent changes in the onset and offset of seasons over the last 20 years? (Please explain)

______________________________________________________________________________
______________________________________________________________________________

3. If you perceived climate change, what changes have you made to your farming to adapt to it? Please list below three major adaptation strategies in order of their importance.

______________________________________________________________________________
______________________________________________________________________________
______________________________________________________________________________

* This section learned from a questionnaire used by (G. A. Gbetibouo, 2009; Katharina Waha et al., 2016)
Part VI

Production and wealth

1. Cultivated crops in the last Meher and Belg seasons

<table>
<thead>
<tr>
<th>Names of crops, vegetables and fruits</th>
<th>Quantity produced in quintal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Meher</td>
</tr>
<tr>
<td></td>
<td>Belg</td>
</tr>
</tbody>
</table>

2. Livestock ownership

<table>
<thead>
<tr>
<th>Livestock type</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxen</td>
<td></td>
</tr>
<tr>
<td>Cow (local)</td>
<td></td>
</tr>
<tr>
<td>Cows (cross breed)</td>
<td></td>
</tr>
<tr>
<td>Immature males</td>
<td></td>
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<tr>
<td>Heifers</td>
<td></td>
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<tr>
<td>Calves</td>
<td></td>
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<tr>
<td>Donkey</td>
<td></td>
</tr>
<tr>
<td>Horse</td>
<td></td>
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<tr>
<td>Mule</td>
<td></td>
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<tr>
<td>Goats</td>
<td></td>
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<tr>
<td>Sheep</td>
<td></td>
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<tr>
<td>Camel</td>
<td></td>
</tr>
<tr>
<td>Chickens</td>
<td></td>
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<tr>
<td>Honey bees (Colonies)</td>
<td></td>
</tr>
<tr>
<td>Others (please specify)</td>
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</table>
Survey II

Rural Household Survey
Interview Schedule

Crop production and switching

Introductory statement:

“This survey is carried out to study farm-level adaptations to climate change in Ethiopia. The data collected will be used only for research purposes and any information provided by respondents will not be transferred to any third party in any form. Thank you for your kind co-operation.”

Household ID _________________________

Woreda_____________ Kebele ___________ Got_____________

Date of interview __________________________

Interviewer _______________________________

Checked by_______________________ Date ________________

Data entry by __________________ Date _________________

Household head

Sex _________ Age _________
Land owned in ha (Meher season 2015/2016)_____________
Land cultivated in ha (Meher season 2015/2016)_____________
1. Please list the crops you cultivated in the previous Meher and Belg seasons (2015/2016)

<table>
<thead>
<tr>
<th>Crop</th>
<th>Land coverage in ha</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Meher</td>
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<tr>
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</tbody>
</table>

2. Is there any crop you newly adopted or permanently stopped growing in the last 20 years?
   a) Yes______ b) No______

3. If your answer is yes, please provide the detail below

<table>
<thead>
<tr>
<th>Crop</th>
<th>Adjustment</th>
<th>Main reason for decision</th>
<th>How long since adjustment, in years</th>
<th>Season (Belg, Meher, both)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Adopted</td>
<td>STOPPED</td>
<td></td>
<td></td>
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1 Reason for adjustment: -
   a) Soil erosion  
   b) Price change  
   c) Climate change  
   d) Pest and disease  
   e) Intra household changes (family size, income etc.)  
   f) Others (please specify)__________________

4. If you chose ‘C’ in question no. 3, please specify which aspect of climate change is most important?
   a) Decline in rainfall  
   b) Increase in rainfall  
   c) Increase in temperature  
   d) Late onset of rainy season  
   e) Late offset of rainy season  
   f) Early offset of rainy season  
   g) Variable onset of rainy season  
   h) Others (please specify)__________________

5. Which one of the following is most important in your crop switching decisions
   (Choose only one)
   a) Self experimentation  
   b) Other farmers experimentation  
   c) Extension advise  
   d) Others (Please specify)__________________
6. Do you have a plan to try new crops in the future?
   a) Yes________ b) No________
   If your answer is yes, please explain______________________________

7. What is the most important barrier in crop switching? ___________
   a) Lack of finance   b) Limitation in skill and knowledge   c) Shortage of labor   d) Shortage of seed e) Land tenure insecurity f) Lack of access to market g) Pest occurrence   h) Soil infertility   i) Others (Please specify)________

10. Have you ever made erroneous crop switching decisions, which you reversed?
    a) Yes________ b) No________
    If your answer is yes, please give one example along with the source of the
        error________________________________________________________

   What do you recommend to address climate change?

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