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IMPLICATIONS OF CLIMATE CHANGE AND ADAPTATION STRATEGIES FOR HOUSEHOLD FOOD SECURITY: EVIDENCE FROM PANEL DATA IN THE NILE BASIN OF ETHIOPIA

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Implications of climate change and adaptation strategies for household food security: Evidence from panel data in the Nile basin of Ethiopia

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Declaration

I hereby declare that this thesis is my own work and has never been presented in any other university or I have not plagiarized in the preparation of this assignment and have not allowed anyone to copy my work. All sources of materials used for this thesis has been properly acknowledged.

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As thesis advisor, I hereby confirm that this thesis is the output of research undertaken by Robel Seifemichael under my supervision and that it be submitted for the M.Sc. degree award.

Confirmed by Advisor: **Alemu Mekonnen (PhD)**

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November, 2016

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This is to certify that the thesis prepared by Robel Seifemichael, entitled: Implications of climate change and adaptation strategies for household food security: Evidence from panel data in the Nile basin of Ethiopia; and submitted in partial fulfillment of the requirements for the degree of Master of Science in Economics (Resource and Environmental Economics) complies with the regulations of the university and meets the accepted standards with respect to originality and quality.

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ABSTRACT

This study identifies factors that determine decision on adoption of individual/combinations of climate change adaptation strategies. It also investigates whether the type and combination of climate change adaptation practices adopted have significant effect on food security of farm households' and analyzes the possible differences between adopters and non-adopters. The study uses a multinomial endogenous switching regression model of farmers' choice of individual/combinations of climate change adaptation strategies and their impacts on household food security index using panel data collected from 909 farm households in the Nile Basin of Ethiopia. The study has the following three main findings. First, factors that determine the adoption decisions vary across individual/packages of adaptation practices under investigation. Secondly, adoption of climate change adaptation strategies improves the food security of farm households and the highest improvement is achieved when adaptation strategies are adopted in combination rather than in isolation. Lastly, those households who adopt have the advantage of becoming food secure than the non-adopter farm household. Moreover, for farm households who applied the adaptation strategies analyzed, except application of crop rotation in isolation, their food security improved and the likelihood of being food secure increased as farm households adopt practices jointly in their farm plot than adopting in isolation or not adopting at all. Hence, policy makers and other stakeholders should work by promoting the use of combinations of climate change adaptation technologies and also providing households with all the necessary inputs to enhance household food security in the study area.

Key Words: Food Security Index, multinomial endogenous switching, Climate Change Adaptation Strategies

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ACRONYMS

CGE	Computable General Equilibrium
ECRC	Environment and Climate Research Center
EDRI	Ethiopian Development Research Institute
FAO	Food and Agriculture Organization
FDRE	Federal Democratic Republic of Ethiopia
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GPS	Global Positioning System
HFBM	Household Food Balance Model
HFIAS	Households Food Insecurity Access Scale
IDRC	International Development Research Center of Canada
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
ILRI	International Livestock Research Institute
IPCC	Intergovernmental Panel on Climate Change
KMO	Kaiser-Meyer-Olkin
LDC	Least Developed Countries
MoWR	Ministry of Water Resources
NOAA	National Oceanic and Atmospheric Administration
OLS	Ordinary Least Squares

PCA	Principal Component Analysis
SNNP	Southern Nations Nationalities and Peoples
TLU	Tropical Livestock Unit
UNDP	United Nations Development Program
UNEP	United Nations Environment Program
UNFAO	United Nations Food and Agriculture Organization
UNICEF	United Nations Children’s Fund
USGCRP	United States Global Change Research Program
WFP	World Food Program

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CHAPTER ONE: INTRODUCTION

1.1Background of the Study

Climate change brought different problems globally which human beings experience in their day to day life. These include flood, drought, changes in seasonal weather, and rise in sea level. Though the problem was less exacerbated in some parts of the world and even caused some positive impacts in crop yield in higher latitude and higher income earning countries, lower latitude and lower income countries experienced negative effects on their agricultural productivity (Kumar *et al*. 2013). This is due to the fact that developing countries possess low level of technology, higher population growth, greater dependence on agricultural activities with lack of knowledge and resource to adapt to the adverse effects of climate variations (Nath *et al*. 2011). As Ethiopia is highly dependent on rain-fed agriculture with farming productivity using traditional technologies remaining low and vulnerable to climate driven irregularities in the agriculture sector. This resulted in higher rate of exposure of the majority of the population to climate related risks (Stige *et al*. 2006).

Moreover, while the sector contributes about 39% of GDP (FDRE 2016), feeding the ever increasing population and attaining food security in the face of climate change becomes more difficult. Unless adaptation measures to increase resilience to climate change are taken, the consequences will even lead to severe food insecurity and be a significant challenge for the economic development of the country.

Like other countries located in the tropics the most important climatic factors that influence crop yield in Ethiopia are seasonal rainfall and temperature. According to Reddy *et al*. (1992), more than 50% of variation in yield of crops is due to climatic variability. Despite the significant growth of the sector in the past few years, Ethiopia experienced a devastating drought last year which restricts the economic growth as well as the food security of households (FAO 2016).

UNDP (2012/13) noted that despite agriculture's significant contribution to Ethiopia's economic development, it will continue to face major challenges related to climate change in the years to come. The vulnerability and poverty mapping in Africa according to ILRI (2006) puts Ethiopia as one of the most vulnerable countries to climate change with the least coping ability. Climate prediction models also show dramatic variation in future rainfall patterns (UNEP 2007). Food security is among the important priorities in Ethiopia. However, the climate change hazards are believed to be the most significant threat. Food security is highly influenced by climate change because of the direct effects on the ability of a given nation to attain food security. These changes affect the four components i.e., availability, accessibility, stability and utilization of food security in one way or the other (FAO 2002a).

Researchers tried to examine the effectiveness of climate change adaptation strategies in attaining food security of households. Among the research findings which address adaptation to climate change, Aemro *et al*. (2012), Diggs *et al*.(1991) and Menberu *et al*. (2014) found that climatic conditions, soil types and other factors which vary by agro-ecology are the influencing factors to farmer's perceptions of climate change and their decision to adopt different adaptation strategies.

Solomon *et al*.(2014) also expressed the significance of examining climate change adaptation based on different agro-ecological settings.

Thus, we note from these research findings that the impact of weather variability and climate change on food security should be examined under the large and multidimensional frame work and also at plot-level by incorporating socio-economic and environmental variables.

1.2 Statement of the problem

Agricultural production and constraints in relation to climate change has been studied by a number of scholars in the last several decades. Different adaptation strategies were proposed by the researchers to the dynamic environment in the agriculture sector at regional or country level in order to reduce the negative impacts of climate change on agriculture. These studies also tried to identify factors affecting adaptation decisions.

Research addressing climate change impacts on agriculture in the Ethiopian case is highly concentrated on farmers' perceptions about climate change, determinants of adaptation strategies, impacts of climate change on crop production and net farm revenue. Deressa (2007), Yesuf *et al*.(2008), Deressa *et al*. (2008), Deressa, Hassan and Ringler (2010), Di Falco *et al*.(2011a) and Di Falco *et al.*(2011b) are some of the studies conducted in the Nile Basin region of Ethiopia looking at the impacts of climate change on agriculture and determinants of different adaptation measures. All these studies did not address food security in a multidimensional manner.

However food security is highly affected by weather variability and climate change as the latter directly affects the ability of a given nation or household to attain food security by affecting food security components (FAO 2002b). Moreover, the impact of climate change on food security should be seen from multi-dimensions including socio-economic, agro-ecological settings and environmental variables at plot-level (Ibid).

In analyzing food security in its multidimensional manner, Jemal *et al*.(2014) explored the determinants of household food security in rural Ethiopia by including three components of food security: availability, accessibility and utilization. Their analysis did not include stability component of food security as well as climate change impacts on food security. Likewise, Abera *et al*.(2011) used panel data analysis to examine multidimensional components of food security. However, their analysis did not include the utilization component of food security due to data limitation and climate change adaptation and temperature impacts were also not included in their study.

Ginbo (2014) addressed those specified gaps above and analyzed climate change and adaptation strategies' implications on household food security in relatively similar agro-ecological zone. This study made a significant progress in Ethiopia in analyzing food security in its four dimensions and also adaptation strategies to climate change. The researcher constructed multidimensional food security index using four indicators representing all dimensions of food security and identified common farm level adaptation options to evaluate the effectiveness of individual strategies in ensuring household food security. This study analyzed household level climate change adaptation strategies in such a way that they were applied to a given farm plot in isolation/individually. On the other hand Teklewold *et al*.(2013) found that adoption of individual/combinations of adaptation strategies resulted in different outcomes/pay-offs for a given farm household. Moreover, Khanna (2001) also pointed out the inter-relationships between multiple technologies while analyzing their adoption decisions is important for obtaining consistent impact estimates of adaptation.

Therefore, this study will add to the existing literature by filling the gaps identified above. This study focuses on identification of determinants of adoption decisions among individual/ combinations of adaptation strategies, analysis of the effectiveness of individual/packages of climate change adaptation strategies for the attainment of household food security (food security which is indexed using the four components: availability, accessibility, utilization and stability) and analysis of whether there is a difference in the food security status of adopter and non-adopter households and within different adoption decisions.

In this study, we estimate the effect of climate change adaptation (individually and/or packages of adaptations) on smallholder farm household food security and also identify the determinants of adoption decision in isolation or as packages. A comparison of the estimated impacts of climate change adaptation in isolation or as packages on smallholder farm households was done among the adopters and non-adopters and within different adaptation strategies.

The research questions addressed are:

- What are household's socio-economic, institutional and plot-level characteristics affecting adaptation decision (individually and/or packages of adaptations) to climate change and variability across time?
- Are plot-level adaptation strategies (individually and/or packages of adaptations)[1] to climate change and variability effective in helping to improve households' food security?
- Is there a difference in the food security index of adopters and non-adopters of climate change adaptation strategies(individually and/or packages of adaptations) in the counterfactual[2] cases?

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[1] Individual Adaptation: adoption of single adaptation strategy, Package adaptation: adoption of more than one adaptation strategy.

[2] Counterfactual cases: what would have happened had non-adopters adopted

- Do adaptation strategies under investigation (individually and/or in combination) result in different outcome (in terms of food security status) with in adopters?

1.3 Objectives of the study

The general objective of this study is to analyze the determinants of decisions to adopt climate change adaptation strategies(individual and/or combinations of adaptations)and their implication on food security of farm households in Nile Basin of Ethiopia. Specifically, based on plot level panel data collected in two waves, our study seeks to achieve the following objectives:

- ✓ To investigate household's plot-level determinants of decisions to adopt individual and/or combinations of adaptation strategies to climate change and variability
- ✓ To understand the effect of application of individual and/or combinations of climate change adaptation strategies at plot-level in helping to improve the food security of farm households
- ✓ To investigate whether there is a difference in the food security index of adopters and non-adopter and also within the application of different adaptation strategies (individual and/or combinations of adaptations) by farm households

1.4 Significance of the study

Agriculture is the main source of livelihood of the majority of the population and basis of the national economy of Ethiopia; it contributed about 39% to the country's GDP and generated close to 74% of export revenues to the country's economy (FDRE 2016).Current global and local climatic variations adversely affect the sector by challenging its ability to play a leading role in the economy.

Let alone becoming a main gear of the economic process by supporting industrial sector in the provision of raw materials and labor, the agricultural sector itself will become unable to feed the ever growing population if current climate change situation persists and worsen in the future unless some adaptation schemes are implemented on time and efficiently.

Therefore, this study will contribute to the existing knowledge of climate change, variability and adaptation strategies (both individual adaptations and combinations of climate change adaptations) in the attainment of household food security in the following ways:

- It will contribute to a better understanding of the empirical linkages between climate change adaptation strategies and households' food security in such a way that it helps to investigate determinants of decisions to adopt individual and/or combinations of adaptation strategies to climate change and variability taking effects of agro-ecology into account.
- The study will help to understand whether application of individual and/or combinations of climate change adaptation strategies helps to improve the food security status of farm households by considering all aspects of food security and using panel data.
- The study will help farmers in selection of best suited adaptation strategies among alternative climate change adaptation strategies under investigation in the study area.

1.5 Scope and Limitations of the Study

This study tries to give an insight about the impact of climatic variables such as rainfall and temperature, determinants of decisions of plot-level individual and/or combinations of adaptation strategies and also their effect on household food security across time.

In relation to the analysis, the study used two-waves of panel data(2014/15 and 2015/16)for the construction of multidimensional food security index and also for the evaluation of plot-level individual adaptation strategies and/or packages of adaptations in Nile Basin of Ethiopia.

One of the limitations of this study was unavailability of data for the period 2014/15 about food security status of households. In order to overcome this problem recall questions were asked to households about their food security status in 2014/15 in the survey that was conducted in 2015/16. The other limitation of the study is the research uses only two-waves of panel data i.e. short period panel data due to unavailability of relatively longer-period panel data. In spite of this the use of panel data is a contribution to the literature as most of the related literature use cross-section data.

1.6 Organization of the Study

The study is organized into five chapters. The first chapter is an introduction including background, statement of the problem, objectives, significance, scope and limitations of the study. Chapter two presents theoretical and empirical literature reviews. The third chapter presents the methodology of the study comprising the data, model specification and methods of data analysis. Empirical findings of the study are discussed in the fourth chapter. The study ends with chapter five where the main conclusions and policy implications are presented.

CHAPTER TWO: LITERATURE REVIEW

2.1 Theoretical Literature Review

2.1.1 Food Security: Concepts and Measurements

Food security can be reflected and expressed depending on situations under consideration. For more than four decades, different attempts have been made to reach consensus on clear and common definition about food security which would help in research and policy formulation. Even a decade ago, there were about 200 definitions in published writings (Maxwell & Smith 1992). This shows the presence of a great deal of differentiation in the definition of food security which ultimately leads to different approaches to food insecurity problems.

Food security as a concept emerged in the mid-1970's, when the global food problems became hot issues in the discussion of international food crisis. During that time, the focus of the discussion was primarily on how the supply side of food can be increased in relation to the ever increasing demand for food which would ultimately solve the unavailability of food to some extent and also price volatility of basic food stuffs.

The issues of famine, hunger and food crisis were also extensively examined following the events of mid-1970. The outcome of the events was redefinition of food security, which recognized that the behavior of potentially vulnerable and affected people was a critical aspect. The other important factor which re-shaped views of food security at the time was the inability of the Green Revolution to bring automatic, rapid and dramatic lead to reduction in poverty and levels of malnutrition.

In 1974, the initial focus of the United Nations Food and Agriculture Organization (FAO) conference was on the volume and stability of food supply. Following the World Food Summit of 1974, food security was considered as: “the availability at all times of adequate world food supplies of basic food stuffs to sustain a steady expansion of food consumption and to offset fluctuations in production and prices”. One can easily see that this definition of food security heavily relied on food supply: availability side and price which were the main concerns at that time.

Following the 1970's FAO's definition of food security, the organization extends its concepts and definitions of food security by the year 1983 to include securing access to vulnerable people to get enough food or availability of food supplies which gives an emphasis on balancing between the demand and supply side of the food security following the definition of food security: “ensuring that all people at all times have both physical and economic access to the basic food that they need”. This definition also has its own drawbacks to express food security in a well defined manner, since it failed to explain whether the food the public got have helped them to perform their active and healthy daily life or not was not addressed in it.

World Bank also got involved in 1986 and tried to solve previously described problems of FAO 1983 definition by assessing whether the food eaten by the households or individuals helped them or not to lead an active and healthy life and they incorporated this in their food security definition of 1983. The World Bank definition of food security is: “access by all people at all times to enough food for an active and healthy life”. It introduced the widely accepted distinction between chronic food insecurity, associated problems of continuing or structural poverty, low incomes and transitory food insecurity, periods of intensified pressure caused by natural disasters, economic collapse and conflicts. This definition includes only two parameters of food security: availability and accessibility of food.

A decade after World Bank’s 1986 definition of food security, World Food Summit adopted the following definition of food security in 1996: “Food security exists when all people at all times have physical or economic access to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO, 1996b).

Even though this definition seems to be complete by addressing those previously specified gaps in defining food security, it only explained the physical and economic access to nutritious food to fulfill the dietary need and also to have healthy life. They left out the social aspect of food security in their definition.

In 2002, FAO has given another definition for food security which incorporates the social aspects in such a way that food security is a situation when “all people, at all times, have physical, social and economic access to sufficient, safe and nutritious food that meets their dietary needs and food preferences for an active and healthy life”. Moreover, this definition emphasized the multidimensionality of food security and it also widely established the four pillars of food security: availability, accessibility, utilization and stability.

In addition to the FAO(2002a) study, food security also got a great emphasis in the IPCC expert meeting on Climate Change, Food and Agriculture of 2015(IPCC 2015). The IPCC experts reached in to a consensus that "The widely accepted definition of food security with four components: availability, access, utilization and stability was a good organizing framework to pull together the desperate elements of food security. Among other benefits, it allows a holistic perspective". In addition to this, the experts believed that there is a great deal of importance to incorporate both qualitative and quantitative measurements in food security analysis. According to FAO's State of Food Insecurity report (FAO 2002a), food security includes four major pillars/component: availability, accessibility, stability and utilization of food. The possible working definition of each component is presented below.

As described by the Asian Development Bank (2012), availability of food is determined by the physical presence of food or domestic production of food grain from agriculture or allied sector in a particular region or place in certain duration and with a given technology inventory levels, local and international trade, commercial imports or food aid; and this mainly focuses on food production.

FAO (2008) also explained availability of food is determined by the physical quantities of food that are produced, stored, processed, distributed and exchanged. From both expressions above one can see that the availability component of food security is mainly concentrated on the existence of food for consumption through different means of acquiring it. Using this notion, we can consider availability of food as the existence of food stocks to the households for consumption.

Accessibility of food refers to having to acquire or entitlement of adequate amounts of food by individuals for nutritious diet (FAO 2006). There may be a situation where food is available in a given country but a given population or households might not be able to acquire the food due to political, social arrangements, conflicts, economic and other reasons (Sen 1981). This definition implies that food availability alone doesn't guarantee a given household or population food security by itself. Moreover, food accessibility can be expressed as the ability of people to obtain food either through production, purchase or transfers. Hence, this component of food security is directly linked with economic ability of the population or households to afford a sufficient amount of food for their survival.

Utilization of food is defined as when a household's ability to absorb and metabolize the nutrients and appropriate nutritional content of the food consumed; and ability of the body to use it effectively. Utilization of food is mainly linked with nutritional value of food, interaction with physiological condition and food safety; and this provides the quality, safety and actual nutrition contents in the consumed food. It is also related to having clean water, sanitation and health care to reach a state of nutritional well-being where the body needs are met (FAO 2006). Therefore, we can relate the utilization component of food security with access to pure drinking water, sanitation and health. This will bring out the importance of non-food inputs in the food security analysis (Ibid).

Food stability is the condition where food is regularly and periodically available in the domestic market so that it also contributes to nutritional security and this includes the impact of natural shocks like floods and droughts on crop production; and this specially focuses on continuity of supply and demand of food grain product (FAO 2009). In order to be food secure a population or households should not risk losing access to food as a consequence of sudden shocks. In addition to this, stability can refer to both availability and access dimensions of food security (FAO 2006). Therefore, stability can be addressed as not to be shortfall of food supply from the household.

As noted by FAO (2003), to evaluate the potential impacts of climate change on food security, "it is not enough to assess the impacts on domestic production in food-insecure countries. One also needs to (i) assess climate change impacts on foreign exchange earnings; (ii) determine the ability of food surplus countries to increase their commercial exports or food aid; and (iii) analyze how the incomes of the poor will be affected by climate change"(FAO, 2003: 365-366). Food security analysis has to depend on multi-dimensional ways and also all food security components should be assessed to address the possible impacts of climate change. Thus, in this study the impact of climate change on households' food security is going to be addressed within a multidimensional context.

2.1.2 Effects of Climate Change on Food Security

The effects of climate change and variability include food insecurity in many parts of the world now a days, especially in developing nations. Food security is directly related to climate change and weather variability because any climatic change and variability can affect a given household or country's ability to feed its household members and the society at large (Ahmad *et al*. 2011). According to FAO (2008), climate change affects all components of food security. The availability of food, access, stability and utilization components of food security are affected by climate change and weather variability in different ways. In the next sections, we will see the effects of climate change on each food security component in a more detailed manner.

2.1.2.1 Effects of Climate Change on Food Availability

Climate change affects agriculture and food production directly by altering the agro-ecological conditions of a given location which results in a decline or rise in production based on specific location characteristics and also it can indirectly affect growth and distribution of incomes in different sectors of the economy, specifically in the agricultural sector. Changes in temperature and precipitation together with sustained emissions of greenhouse gases will bring changes in land suitability and crop yields (Schmidhuber and Tubiello2007). Boko *et al*. (2007) also note that climate change and variability directly affect agriculture sector which ultimately influences the availability component of food security.

Despite production, import and export policies have influence on the availability dimension of food security, "adequate domestic production, reliable import capacity, food stocks, (effective and adequate), social protection measures, transportation infrastructure", climate change adaptation strategies play the biggest role in food availability (Ziervogel and Ericksen, 2010, Coates *et al.*2007, and Dana 2013).Even though the impact of climate change and weather variability differs across different locations as stated earlier, warming of more than 3^{o}C is expected to have negative effects on production in all regions (IPCC 2007c).

Climate change will affect the availability of food in the world and it will decrease the availability of food in LDC's since their adaptive capacity is somehow limited (Nath and Behera *et al*. 2011). An assessment of the impact of climate change on food production of 2020 perspective by Liliana (2005) indicates, about two thirds of arable land in Africa is expected to be lost by 2025 due to decreased rainfall and this will reduce yields with an estimation of up to 50 percent in some Sub Saharan countries where 96% of the cultivated land depends on rain-fed agriculture with limited adaptive capacity to the changing environment (FAO 2007; Liliana 2005). Therefore, climate change has huge and significant impact on the availability dimension of food security component.

2.1.2.2 Effects of Climate Change on Food Accessibility

Recalling to the definition above, food accessibility is the ability of an individual to acquire food either through its production or purchase. According to Amartya Sen (1981), having access to food is not a matter of having enough to eat, rather it is a matter of there being enough to eat as a result having sufficient access to entitlements. FAO (2006) expresses entitlement of food as "the set of all commodity bundles over which a person can establish command given the legal, political, economic and social arrangements of the community in which the person lives". This definition well explains entitlement of food as it is intertwined with so many aspects where the given entitled individual or household live with.

The situation becomes more complex when we note that most of the food in the world does not produced by individual households, rather they acquire food through buying, trading and borrowings (Du Toit and Ziervogel 2004). In such situations and also in the face of climate change, acquiring the required amount of food for consumption by individuals or households becomes highly likely a difficult task.

Moreover, food production and availability of food alone doesn't guarantee access to food by the households or individuals. Rather, some minimum amount of households or individual level asset holdings and entitlements enables one's food access. This is because households asset or entitlements can influence a given households ability to purchase sufficient inputs for their agricultural practices which increase the productivity from the sector and it can also positively affect the coping ability whenever a shock arises in the process of production.

Not to be able to have the required amount of asset holdings and entitlements will lead to the decline in the livelihood security and access to food by the individuals or households (Confalonieri *et al*.2007). The other important factor that can hinder households or individuals to access food is, as a consequence of climate change, the national food yield will decline and ultimately the price of food stuffs will rise up. This will challenge the households' ability to satisfy their food consumption through buying. This situation is more serious when it comes to low income households. An increase in food prices has a real income effect, with low-income households often suffering most, as they tend to devote larger shares of their incomes to food than higher-income households do (Thomsen and Metz 1998).We note from this discussion that the accessibility component of food security is influenced by the climate change and/or weather variability.

2.1.2.3 Effects of Climate Change on Food Utilization

The utilization component of food security is mainly concerned with how food is used and it also considers the nutritional aspects of food. Even though food availability and accessibility are the necessary conditions for food utilization, they are not sufficient conditions to reduce malnutrition. For instance, a given household which has physical access as well as economic access to food can fall in to food insecurity if he/she could not be able to get the required and balanced food out of consumption (Negin, Rome, Karuti, Kanzo 2009).

According to the study by Badolo, KindaSomlanare (2012), there are three main ways in which climate change directly affects micronutrient consumption: by changing the yields of important crop sources of micronutrients, by altering the nutritional content of specific crops or by influencing the decisions to grow crops of different nutritional value. Increased CO_2 concentration can lower the protein content in various food crops, particularly in the context of low nitrogen inputs. This situation is much more aggravated in poor areas of the world where less nitrogen application in their farm plots and also much of their dietary protein came from the cereals produced. Rosenzweig and Binswanger (1993) and Badolo, KindaSomlanare (2012) show that climate can force the decisions made by the farmers about what crops to grow. This shifting planting decision of crops which is done as a result of climate change can alter micronutrient availability for households' consumption.

Moreover, food utilization is intertwined directly with water availability and quality, sanitation systems and it is also influenced by water-borne, food-borne, vector-borne and other infectious diseases (FAO 2002b; UNICEF 2000). The availability of clean and safe water is affected by the climate change which ultimately affects the sanitation of the households. Climate change can have its effect on the incidence of disease outbreaks, for instance prolonged drought and heat waves increase the risk of meningitis outbreaks. On the other hand, prolonged flood can increase the probability of cholera outbreaks (McMichael *et al*.2006; Canfalonieri *et al*.2007). This will have an impact on the affected population by lowering their body ability to effectively use the food they consumed. One can easily see that, utilization component of food security is a very significant component of food security in a changing climate but on the contrary it is the least studied component.

2.1.2.4 Effects of Climate Change on Food Stability

In order to be food secure a given population, household or individual must maintain the availability, accessibility and utilization dimensions of food security and they should be stable over time and they should not be affected negatively by natural, social, economic or political factors such as risk of adverse effects and sudden shocks caused by economic and climatic changes. According to FAO (2002a), "To be food secure, a population, household or individual must have access to adequate food at all times and should not risk losing access to food as a consequence of sudden shocks (economic or climate crisis) or cyclical events (seasonal food insecurity). Thus, stability of the food supply depends on both the availability and accessibility dimensions of food security".

In reality, dimensions of food security are getting affected by different climatic and economic variations across time and space. For instance in rural areas that depend on rain-fed agriculture where their food supply is mainly depends on the natural environment, the changes in the amount and timing of rainfall within the season and an increase in weather variability are likely to affect the stability of food (FAO 2008).

It should also be noted that extreme events including excessive high temperature which is greater than 3ºC as described in the IPCC (2007c) at the crucial periods of agricultural crops growth, droughts and floods are among the threats to the stability of food access and utilization (Anna Antwi 2013). In such cases, conflicts around scarce resources like water and land brought migration of people as a result of drought can arise in different locations which result in conflicts in those areas escalating the effect on food insecurity and under-nutrition (Ibid).

Moreover, the stability of food can depend on the local and regional food production (for availability) and also on the reliability and price of food imports (food access) as described in Cohen and Garrett (2009). Therefore, the stability of food for individual or household consumption can be affected by climate change and weather variability as a function of all driving factors mentioned above.

2.1.3 Climate Change, Agriculture and Food security: theoretical aspects

Agriculture is a sector which is highly vulnerable and sensitive to climatic shocks. In addition to its exposure and sensitivity to climatic shocks, it is a sector which needs a greater emphasis since it absorbs huge amount of labor force to create employment opportunities and also serves as the economic gear for most of developing nations (FAO, IFAD and WFP 2015).

Though, the delicateness of this sector’s link with climate change and weather variation not only directly related to the sector itself but also to the overall economic environment and it becomes the issue of survival for the developing world. Hence, because of their economic activity dependence on climate and/or weather sensitive agricultural production system, it is highly likely that their overall economic activities and social wellbeing is also vulnerable to climate change and weather variability.

Moreover, food security which is one of the main problem in the world (severe problem for the developing ones') now a day's directly get affected by agricultural productivity fluctuations and those agricultural productivity fluctuations are affected by climate changes and weather variations. Agriculture is highly dependent on specific climatic conditions. Trying to understand the overall effect of climate change on our food supply and food system can be a very difficult and complex task.

This is because, for instance, increase in temperature and carbon dioxide (CO_2) concentration till some level can be beneficial for crops in some places whereas it might affect the productivity and /or even the growth of crops in a negative way in other places (USGCRP 2009). Climate change can have different types of impacts on agricultural productivities across diversified variety of crops and locations. As stated earlier, warmer temperature might have a positive impact on production of crops in some areas of the world by making the productivity faster.

However, if warming exceeds a crop's optimum temperature, yields can decline. For any particular crop, the effect of increased temperature will depend on the crop's optimal temperature for growth and reproduction given by the nature itself (USGCRP 2009). Disrupting this natural process would lead us not to meet food security targets. High variation in environmental factors such as increase or decrease in rainfall, temperature and others can either positively or negatively affect the productivity of the agricultural sector. Thus, giving greater emphasis to changes in climatic variables on agriculture to attain food security is quite significant and vital (Greg *et al*. 2011).

FAO, IFAD and WFP (2015) note that climate change intensifies the risk of natural hazards through altering rainfall and temperature patterns which increased the frequency of occurrence and intensity of extreme events such as drought and flooding. Negative impacts of climate change are already being felt on the agriculture sector by affecting major crops, livestock production and fisheries (IPCC 2014). In relation to climate change effects, areas of the tropics which have higher exposure to climate change are characterized by high food insecurity (IPCC 2014) and they suffer more from the consequences of climate change. Among the tropic countries, Ethiopia is one of the country's most vulnerable to climate change with less coping ability to respond (Orindi *et al*.2006; Stige *et al*.2006).Climate prediction models also show the presence of dramatic variations in the future rainfall patterns of the country.

Even though the potential and actual irrigated area was not precisely investigated, Belay and Bewket (2013) estimate irrigable land in Ethiopia varied between 1.5 and 4.3 million hectares while others put it at about 3.5 million hectares (MoWR 2001; Awlachew *et al*.2005; Makobe *et al*.2011). World Bank Green Book report of 2014 also puts agricultural irrigated land as% of total agricultural land at about 0.5 percent. It shows there is still huge gap between the irrigated land and the potential that the country has, since Ethiopia is considered a water tower of Africa (Makombe *et al*.2007). Thus, in spite of there is huge potential for irrigation, most of the population is heavily dependent on rain-fed agriculture practice. Hence, the country’s agriculture is more susceptible to climate driven food insecurity (Yesuf *et al*.2008).

Climate change impacts have their own effects on the livelihood assets, food production and distribution channels as well as altering the purchasing power and market structure.

The impacts of climate change can be both short term which resulted from more frequent and intense weather events and also long term changes which prevailed in changes of temperature and precipitation patterns entirely (FAO 2008). Hence, the potential impacts of climate change on food security should be addressed within larger and multidimensional framework.

2.1.4 Rationale for Climate Change Adaptations

The susceptibility of agricultural sector to climate change and weather related shocks makes climate change adaptations as a solution. Adaptation to climate change involves deliberate adjustments and measures in a natural environment or human systems and behaviors in order to minimize occurrences of risks to people's lives and their livelihoods (FAO2008).

IPCC (2007a) notes adaptation to climate change requires making preventive adjustments and decisions to get ready for expected climate changes and variability, in order to moderate the harsh situations and exploit beneficial opportunities resulted from climate change. IFPRI (2007)defines adaptation as the process of improving the society's ability to cope with the changes in the climatic conditions across time scales from short term fluctuations (e.g., seasonal to annual) to long term changes (e.g., decades to centuries).

With regards to the level of selection of adaptation options to minimize the negative consequences and maximize the benefits from a given climate change phenomenon, there are different approaches to adaptations that can be implemented at different levels and also by different actors. Adaptation to climate change generally can take place at micro-level or macro-levels depending up on the existing climate change situation and the approach used to cop-up with. Those adaptations which are applied at farm level, use micro-level of analysis and also focused on the decision making by farm households are characterized as micro-level adaptation and if the adaptation can take place at the national or regional level and covers wider perspectives, like domestic and international policies, it is referred as macro-level adaptation (Kandlinkar and Risbey, 2000).

The difference between the two adaptation approaches lie on the levels at which they treat a given climate change situation and the measures taken to avoid/ minimize the effects of certain climatic shocks, i.e., micro-level adaptation focuses on tactical decisions at which farmers make in response to seasonal variations in climatic, economic and other factors. This is farm-level decision making that happened over a very short time period. Macro-level adaptation focuses on strategic national decisions and policies to tackle climatic shocks in a larger scale and give emphasis to long term changes to happen in a coordinated manner (Ibid).

Adaptation to climate change becomes the issue of survival in the face of dramatic changes in the climatic situation now a days. In Africa, where the majority of the population directly rely on rain-feed agriculture to get their food and livelihoods any changes in the precipitation level will lead to a major risk of food insecurity and also impose negative impacts on livelihood of households. The situation becomes more vivid and realized in the IPCC’s Fourth Assessment Report (IPCC 2007) which gave warning for African countries, their yields from rain-fed agriculture will fall by as much as 50% by the year 2020, if the production practices remain unchanged.

The IPCC’s report also explains how the situation is stiff and the need for timely implementation of effective and efficient adaptive measures in Africa’s agriculture sector. Likewise, climate change influences becomes vivid in Sub-Saharan Africa countries: experiencing decreased precipitation and increased drought conditions as measured by analyzing stream flows, lake levels and soil moisture (NOAA 2011).

The current, El Niño is an example of climatic shock which affects the rain-fed agriculture of the East African region as a whole, particularly and severely affect Ethiopia since the country's 15 million people are in need of food assistance according to FAO's, "2015-2016 El Niño Early action and response for agriculture, food security and nutrition" (FAO 2016).

Considering this and the ever increasing population pressure and food demand enveloped by intense climatic shocks will force the agriculture sector to move along with and rationale for applications of climate change adaptations. For a country like Ethiopia with higher level of exposure to climate change variations, higher dependence on rain-feed agricultural practices with less coping capacity, the rationale of effective and efficient application of adaptation strategies becomes natural.

2.2 Empirical Literature Review

Before going to detailed empirical reviews on the impact of climate change on agriculture and food security analysis, we need to see different methodologies and the level of analysis at which they are based upon and also advantages and limitations of them in the literature.

In order to make analysis about impacts of climate change, there are two approaches in the literature which address impacts of climate change: partial equilibrium approaches and general equilibrium approaches. Partial equilibrium models base their analysis on the part of the overall economy such as a single market (single commodity) or subsets of markets or sectors. However, general equilibrium models (economy-wide models) are analytical models which treat the economy as a complete system of interdependent components, i.e., it aims to capture the links between all sectors of the economy (Zhai *et al.*2009; Sadoulet & De Janvry 1995).

2.2.1 Partial Equilibrium Models

According to Mendelsohn and Dinar (1999) and Zhai (2009), there are three basic partial equilibrium approaches that have been developed to assess the impacts of climate change on agriculture. Namely: Agro-ecological zone models, Crop simulation models and Ricardian models. Explanations for each of the partial equilibrium models followed by their strengths and weakness are presented below.

2.2.1.1 Agro-ecological Zone Models

Agro-ecological zone model (crop suitability approach) is one of the partial equilibrium method of analysis which examine the suitability of various lands and biophysical attributes for crop production. This model allows us to make identification and distribution of potential crop producing lands by using crop characteristics, existing technology, soil and climate factors as determinants of suitability for crop production (FAO1996a).

Thus, as climate is introduced in the model as one determinant of suitability of agricultural land for crop production, it can also be used to predict the impact of climatic variables on agricultural outputs and cropping patterns (Du Toit *et al*. 2001; Xiao 2002).

2.2.1.2 Crop Simulation Models

Crop Simulation (agro-economic) approach is a type of model which is based on the data from well controlled experiments where crops are grown in field or laboratory settings by using different simulations of climate and CO_2 levels, hence it helps to estimate crop yield responses (Zhai *et al.*2009).

In the crop-simulation (agro-economic) model, tests of simulations on different types of crops and farmers' response to specific crops and crop varieties under climatic and other conditions receive emphasis in the model.

Moreover, the approach incorporates activities undertaken as farm managements like modeling the impacts of changing timing of field operations, crop choices and adding irrigation (Adams1999; Schimmelpfenning *et al*. 1996). In this model therefore, the changes in yields are incorporated into economic models that predict aggregate crop outputs, prices and net revenue (Mendelsohn and Dinar1999).

2.2.1.3 Ricardian Models

The Ricardian model is a cross-sectional approach which assesses cross section of farms under different climatic conditions and examines the relationship between the value of land or net revenue and environmental and other socio-economic factors (Mendelsohn *et al.*1994). The Ricardian approach regresses farmland values against climatic, economic and other factors in order to estimate the economic impacts of climate change and other factors on farm activities and performances (Mendelsohn and Dinar 1999; Mendelsohn 2000; Mendelsohn *et al.*1994 and Mendelsohn *et al.*1996). The model allow us to incorporate private adaptation strategies and measuring its costs or benefits when it is applied to a given farmland by measuring the economic damages (i.e. costs which are causing economic damages reflected in reduction of net revenue or land value which is proxy by capitalized net revenues from farm land) induced by climatic factors.

Thus, to fully account for the cost or benefit of adaptation, the relevant dependent variable should be net revenue or land value (capitalized net revenues), and not yield (Mendelsohn and Dinar 1999); Deressa and Hassan 2009).

2.2.2 General Equilibrium Models

Computable general equilibrium model (CGE) is a type of economic model which assesses the economy-wide policy impacts and also environmental issues (Oladosu *et al.*1999).This method combines the abstract Walrasian general equilibrium structure formalized by Arrow and Debreu with realistic economic data to solve numerically for the levels of supply, demand and price that support equilibrium across a specified set of markets (Peterson 2003; Wing 2004). Computable general equilibrium (CGE) models are applicable to address the economy-wide environmental impacts by capturing the effects of exogenous changes to overall economy in an integrated manner and also it can provide an insight into micro-level impacts on producers, consumers and institutions (Oladosu *et al.*1999).

Table 2.2.1 Advantages and limitations of models used to assess impacts of climate change on agriculture

No	Approaches used to assess impacts of climate change	Model Types	Advantages	Limitations
1	Partial Equilibrium Approaches	Agro-ecological Zone (Crop Suitability) Models	✓ Applicability of the method when little climate research has been done and also where data constraints may make the use of other methods difficult. ✓ Having full knowledge of potential impacts of future technology and genetic strains on specific parameters, modeling of future climate sensitivities can be done based on detailed Eco-physiological relationships (Mendelsohn 2000).	✓ Without explicitly modeling all of the relevant components, it becomes impossible to predict the final outcomes. It is a difficult and complicated task to build a general model which will help us to predict actual yields across locations, i.e., complexity of the method. ✓ Adaptations included in agronomic models fail to account for economic considerations and limitations in human capital and other resources that affect actual farm-level decisions.
		Agro-Economic (Crop simulation) Models	✓ The model will allow us for detailed understanding of the biophysical responses, as well as adjustments that farmers can make in response to changing climatic and other conditions Adams(1999); Schimmelpfenning *et al.*, 1996). ✓ It is suitable to integrate effects of carbon dioxide fertilization.	✓ Adaptations included in agronomic models fail to account for economic considerations and limitations in human capital and other resources that affect actual farm-level decisions (Mendelsohn 2000). ✓ It fail to account for the diversity of factors that affect production in the field since it is a controlled experiment (Adams *et al.*1998a). ✓ Very high cost implications to undertake the experiments and also for data collection Mendelsohn,(2000); Adams (1999) makes it difficult to implement the method widely, especially in developing countries. ✓ It do not consider crop's switching. ✓ It is crop and site specific method.

No.	Approaches used to assess impacts of climate change	Model Types	Advantages	Limitations
		Ricardian Model	✓ Incorporates farmer adaptation by including decision making changes that farmers would make to adapt their operations to a changing climate. ✓ It is cost effective, since secondary data on cross-sectional sites can be relatively easy to collect on climatic, production and socioeconomic factors (Deressa2007). ✓ Easy to Estimate compared to other partial equilibrium models.	✓ The model assumes constant prices which leads to not to be able to estimate the effects of price changes, hence welfare calculations will be biased Cline,(1996). The cross-sectional approach only measures the loss as producer surplus from climate changes. It takes no notice of price change that would occur if supply changed which leads to omission of consumer surplus from the analysis i.e. The damages are under estimated on the other hand benefits are over estimated Mendelsohn , (2000). ✓ The model does not take into account the fertilization effect of carbon dioxide concentrations (higher CO2 concentration can enhance crop yield by increasing photosynthesis and allowing more efficient use of water) (Cline1996; Mendelsohn and Tiwari2000). ✓ The model is intended for comparative static analysis, not year by year dynamic analysis. ✓ Analysis is focused on the economic dimension of agriculture and only indirectly on other dimensions (e.g. biological and social) ✓ Assumes a partial equilibrium model and does not consider relationships with other sectors.

2	General Equilibrium Approaches	Computable General Equilibrium (CGE)	✓ The model address the impacts of climate change on the overall economy and its impact across different sectors of the economy as well. It explain the interactions between agriculture and other sectors of the economy (Zhai *et al.*2009). ✓ It explain the big picture of climate change and its impacts on the overall economy.	✓ The complexity of the method makes it difficult most of the time to apply it and CGE is often considered as "Black Box" , since the results from the analysis cannot be meaningfully traced to a particular data input parameters, algebraic structure or method of solution Wing, (2004). ✓ The model is relied on consistent and up-to-date data which is not easily constructed or readily available most of the times. i.e. All CGE models require a data set which must be constructed consistently from input-output tables, social accounting matrices (SAMs), environmental variables such as GHG emissions etc. must be linked to the economic data which makes it hard and time taking to be managed and needs well coordinated personnel's to do effective CGE analysis. ✓ Absence of money or financial assets in most CGE models: it is not easy to incorporate money and financial assets into a CGE model, therefore, most CGE are used only for study of the 'real' economy where, only relative prices matter. Most CGE models therefore, cannot be used for the analysis of monetary or financial policies.

2.2.3 Empirical Literature on Climate change, Agriculture and Food Security

A number of studies have been conducted to assess the impacts of climate change on agriculture and food security in different countries. The studies can be categorized in to two main groups based on approaches used to evaluate the impact of climate change on agriculture and food security as described above. These two approaches are based on economy-wide and micro-level analysis. Generally, both economy-wide and micro-level studies reviewed here found the presence of negative impacts of climate change on agriculture and also on the attainment food security.

Among the studies conducted to estimate the economy-wide impacts of climate change are Nordhaus and Boyer (2000); Mendelsohn, Schlesinger and Williams (2000); Tol (2002) and the review of the literature in Stern (2007) assesses climate change impacts on economic growth globally and point to mean GDP losses between 0% and 3% of the world GDP for a 3^{o}C warming level from the year 1990 up to 2000. However, these estimates of damages are often incomplete: they rarely cover nonmarket damages, the risk of local extreme weather, socially contingent events or the risk of large temperature increases and global catastrophes[3].

Thurlow *et al*.(2009) examined the impacts of climate variability and change on economic growth and poverty in the case of Zambia using dynamic Computable General Equilibrium (CGE) and hydro-crop models jointly. The results from their investigation show that climate change drags-out huge amount of money from Zambian's economy.

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[3] The study by Mendelsohn covers only market impacts; on the other hand, Tol assessed market and non-market impacts of climate change. In addition to those studies, Nordhaus and Boyer, and Stern cover market and non-market impacts as well as catastrophic risks.

The estimated amount of money which will be pulled-out from the economy due to climate change driven impacts is about USD4.3 billion over a 10-year period and might reach as high as USD7.1 billion in a worst-case rainfall scenario.

The other study which examines the long-run impact of climate change on agriculture globally using a dynamic CGE model of the global economy with a focus on China and Southeast Asia was done by Zhai *et al.*(2009) and Zhai and Zhuang (2009) respectively. The studies predicted that climate change would significantly affect global agricultural production (crop production, livestock and processed food production) negatively by the year 2080.

The forecasted simulation results for Sub-Saharan Africa (SSA), Latin America and South Asia showed that the countries would hardly be hit by climate change impact on their crop production and each of these countries would experience a fall in their crop output by 30%, 24% and 20% respectively in 2080. It is also showed in Zhai *et al.*(2009) that the result of a fall in the crop production in China caused by climate change impact will be reflected in other sectors of the economy. For instance mining, manufacturing and service sectors of the economy will be affected by rising input costs and resource diversion towards the agriculture sector which leads to decline in the percentage share contribution of agriculture sector to China's economy.

For the Ethiopian economy, Gebreegziabher *et al.* (2011) modeled the impacts of climate change on the overall economy using dynamic Computable General Equilibrium (CGE) model. The simulated results of the model on the impacts of climate change-induced variations in the productivity of land in the country's economy for the period 2010-2060 shows, over a 50-year period, a significant amount of decline in the agricultural productivity which leads to a 30 percent less average income compared with the possible outcome in the absence of climate change in the country.

They also projected that the effect of climate change on the overall economy will be getting worse after the year 2030.

Tadele and Ashenafi (2012) examined the impacts of climate change on agriculture and its implications for food security in the case of Ethiopia by using Computable General Equilibrium (CGE) model which was based on 2005/06 Social Accounting Matrix of Ethiopia. Their simulation was done on the basis of agro-ecological zones (AEZs) of the country which helped them to see the impacts of climate change on agriculture and its implications for food security across different agro-ecological settings. The results of the CGE model simulation shows that climate change has a negative effect on economic growth of the country. To see the effect clearly, for a 3.26^{o}C increase in temperature and a 12.02mm decline in precipitation there will be a 9.71% loss in crop production and their CGE model simulation indicates that real GDP will also decline by 3.83% (Ibid).

Moreover according to the simulation results of their study, different sectors of the economy are affected by the climate change impacts negatively and also different agro-ecologies are affected differently: the highland part of the country is the one which is highly affected by climate change impacts when it was compared with the other agro-ecological zones under their investigation. In the future, according to their forecasts, the situation becomes more devastating since it is known that the highland parts of the country are the main producer of food crops in the country is the one which is going to be affected by climatic shocks. Their findings was extended in to household level and found that household livelihoods are negatively affected from the consequences of climate change impacts and those poor households who live in smaller urban centers are the biggest losers in income and welfare in the face of changing environment (Ibid).

Those studies reviewed above assess and estimate the impact of climate change on the overall economy by using Computable General Equilibrium (CGE) models. Another approach is analysis at micro-level and such literature is briefly reviewed below.

Deschenes and Greenstone (2007) used Ricardian approach to see the effect of random year to year variation in temperature and precipitation on agricultural profits in the case of the United States and they found that climate change will increase annual profits in United States agriculture by 3.4% and the changes in temperature and rainfall will almost have no effect on yields among the most important crops. Using similar approach for the case of India, Guiteras (2009) estimate that the major crop yields in India will decline by 4.5% to 9% in the medium term and by 25% in the long-run scenarios. These results show that some countries and locations might benefit from a given climatic situations while others getting worse from such phenomenon.

Seo and Mendelsohn (2009) examine the distribution of climate change impacts across the sixteen Agro-Ecological Zones (AEZs) of eleven African countries using the Ricardian approach. They used a sample of 9,579 observations in their study and found African crop net revenue is very sensitive to climate change. Both the revenue from crop and livestock production are resilient to climate change impacts. According to their estimates under the hot and dry climatic scenario, the average damage to African agriculture will reach up to 27% by the year 2100.On the contrary, under the mild and wet climatic scenario, African farmers earning will increase by 51% and benefit from climatic changes but their revenue will fall by 43% if future climate became hot and dry. Their analysis also showed that different agro-ecological zones of Africa react differently to climatic changes. For instance, currently productive areas such as dry/moist savannah are more vulnerable to climate change while currently less productive agricultural zones such as humid forest or sub-humid agro-ecological zones become more productive in the future due to climatic variations in those specified areas.

The other study by Gbetibouo and Hassan (2005) measures the economic impact of climate change on major South African field crops (Maize, Sorghum, Wheat, Sugarcane, Groundnut, Soybean and Sunflower) using the Ricardian approach. The results of their study shows that, the selected field crops were sensitive to marginal changes in temperature than to marginal changes to precipitation. An increase in the temperature positively affects net revenue whereas the effect of a reduction in the rainfall have a negative impact on net revenue from the production of those crops specified above. The study also highlights the importance of locations in dealing with climate change impacts. This is because climate change impacts will differ between agro-ecological regions and even within the same agro-ecological zones of the same country or region.

Molua (2002) employed a Ricardian approach in Cameroon to analyze whether the revenue from farm practice have a relationship with climate variables in the southwestern part of the country using a sample of 110 farmers in the study. Their analysis was based on controlled soil and water conservation practices in order to capture the marginal effects of precipitation on farm income. The study finds that the marginal impact of precipitation on farm income was about 38%.

Their study did not include different types of plot characteristics which can have significant impact on the productivity of a given farm plot and also the role of temperature as a climatic factor was not included in their analysis. In addition to this, household characteristics were not also incorporated in the analysis which decreases the explanatory power of their study to estimate climate change effects on the revenue from farming practices. Moreover, their food security analysis was not based on the multidimensionality nature of food security and it doesn't also take in to account the time dimensions in their analysis since they undertake a cross-sectional analysis.

Helmyand Samia (2007) for Egypt and Kabubo-Mariara (2006) for the case of Kenya assess the economic impact of climate change on agriculture using Ricardian approach based on a sample of 900 and 816 households respectively. They found that an increase in temperature will negatively affect the revenue from the agriculture sector of both countries. The results from the two studies show that the temperature component of climate change is much more important than that of the precipitation component. Generally the two studies conclude that climate change affects crop productivity in the two countries which ultimately leads to decline in the revenue from crop production.

For Ethiopia, Mintewab *et al*.(2014) assessed the impacts of weather and climate change measures on agricultural productivity of households measured in terms of crop revenue in Amhara regional state of Ethiopia from 1,500 sampled households and four waves of data from each of the selected households by using the Ricardian approach. They found that extreme temperature values have consistently negative effects across seasons and crop types. It is also expressed in their findings that the impact of temperature varies across crops and seasons for a single crop type and this highlights the heterogeneity of the impacts of climate change even within a farmland. The other important and interesting result of their research was that lesser role is played by rainfall than temperature in Ethiopia's agriculture which was contrary to expectations for rain-fed agriculture.

The research by Deressa (2007) analyzes the impacts of climate change on the Ethiopian agriculture using the Ricardian approach. Their study was based on data from 11 of the country's 18 agro-ecological zones which represents more than 74 % of the country and surveyed 1,000 farmers from 50 districts. The research results indicate that an increase in the temperature and decrease in precipitation would affect the Ethiopian agriculture sector.

The marginal impact analysis shows that for a unit increase in temperature during summer and winter seasons of the country net revenue per hectare would reduce by USD177.62 and USD464.71 respectively.

On the other hand the marginal impact of increasing precipitation during spring seasons would increase net revenue per hectare by USD225.09. Moreover, based on different climatic scenarios in their analysis, decreasing precipitation appears to have a more devastating impact than increasing temperature. Those studies which are undertaken in Ethiopian case using the Ricardian approach did not incorporate adaptation measures taken by farmers to a given climatic changes which would have minimizing effect to costs related to climatic shocks and maximize net revenue from agriculture.

Reviewed studies above address the impact of climate change and variability on the agriculture sector directly. On the other hand they did not address households food security in its multidimensional nature. The studies were concentrated on the production side of food only and they presented the impact of climate change and variability on farm revenue and crop yield gained from a given farm plots under investigation. Nevertheless, analyzing the impact of climate change and weather variability on household food security attainment needs to be addressed in a more inter-related and intertwined environment with different factors that can determine household food security in addition to crop production.

Among those studies which address the impact of climate change on food security, Tegegn (2014) examines the effect of climate change and variability on food security status of the households and their adaptation strategies in Damot Woyde Woreda, Ethiopia using household food balance model (HFBM) and Households food insecurity access scale (HFIAS).

Based on a sample of 117 households taken from two agro-ecological zones (Kolla and Dega agro-ecologies), their analysis shows that the prevalence of food insecurity is more severe in low-land agro-ecology than that of the counterpart. Moreover, their analysis explain households which have larger family size, smaller number of livestock, smaller land holding, lower land fertility are likely to be food insecure households in the study area.

Agricultural production in the study area also vary from one agro-ecological zone to the other due to their varied climatic conditions. But their study missed-out the stability component of food security from the analysis since it considers only availability, accessibility and utilization components of food security.

Those studies reviewed above did not address the multidimensional aspects of households' food security. With regards to addressing this issue, Abera *et al.* (2011) put a milestone for the case of Ethiopia except not including the utilization component of food security in its model due to data inconsistency faced by the researcher. They used three rounds (1994, 1999 and 2004) of panel datasets to analyze the effect of rainfall shocks on Ethiopian rural households' food security and vulnerability over time while controlling for a range of other factors.

They generate time-variant multidimensional household food security index which is composed of three dimensions of food security: availability, accessibility and stability components using principal component analysis; and they used the resulted food security index as a dependent variable in the identification of the determinants of food security over time by using fixed effects instrumental variable regression method. They found that the level and variability of rainfall are important determinants of persistent household food insecurity and vulnerability. They also found that having larger household size, male household headed, owning more livestock and participation in the local saving groups positively affect food security.

Limitations of the study by Abera *et al.*(2011) include not including the utilization component of food security in their model due to the inconsistency of the available data when they built multidimensional food security index. They also do not incorporate the effect of temperature on the attainment of food security. The authors recommend further studies to address the utilization component of food security and also incorporation of different agro-ecological settings in their food security analysis.

Ginbo (2014), came up with a multidimensional food security index which solves some of previously raised limitations of the research by Abera *et al.*(2011) and incorporates four dimensions of food security: availability, accessibility, utilization and stability components. Based on cross-sectional data from a sample of 148 households in Boricha district of Southern Nations Nationalities Peoples Regional state (SNNPR) of Ethiopia, Ginbo (2014) assessed the impacts of climate change, variability and households adaptation strategies in the attainment of food security of the study area. The researcher applied principal component analysis on the food security components of those selected households in order to categorize them in to food-secure and food-insecure groups. He then use this categorization as a dependent variable in the Two-Stage Least Square estimation framework and combined it with different farm level adaptation options to evaluate the effectiveness of individual strategies in insuring household food security.

The results show that increased temperature and unfavorable rainfall conditions would have a negative impact on household food security. Moreover, in relation to adaptation strategies access to agricultural extension, credit, climate information and market significantly enhance adaptation decisions by the targeted households.

Even though the research by Ginbo (2014) is quite impressive in addressing impacts of climate change on households' food security from a multidimensional perspective, different determinants/factors that affect food security were not included in his work which could have had a significant power in explaining the food security situation in his multidimensional food security model. In relation to addressing climate change impacts on food security over a wide range of geographic settings, Ginbo's research was confined within a relatively similar agro-ecology of Boricha district which prohibits his research work to assess whether there is a difference in different agro-ecological zones.

Moreover, Ginbo (2014) did not include plot characteristics under which households perform their agriculture practices which could affect the productivity of a given farm-plot. However his research work did not incorporate analyzing combinations of different climate change adaptation strategies, rather he analyzed the adaptations as if they were individually applied to a given farm plot. On the other hand, Teklewold *et al.*(2013) gave emphasis to applications of climate change adaptation strategies independently and/or in combination which may result in different pay-offs for a given farm household. Khanna (2001) also pointed out recognition of the inter-relationships between multiple technologies while analyzing their adoption decisions is important for obtaining consistent impact estimates of adoption. Moreover, since the research work by Ginbo (2014) was based on cross-sectional data of 148 households in the study area, it wouldn't allow to see the time dimensions of food security and also how households behave for a given climatic shock across time periods.

Ayala (2014) also examined the effect of climate change on household food security and vulnerability to future food shortfalls by constructing a multidimensional food security index for Zambia.

The study used panel data of three waves which holds a total of 4,286 households who were re-interviewed in all three rounds of their study. Climatic variables such as temperature and rainfall data were also used to undertake the analysis of climate change impacts on household food security in the study area. In doing so, the author used three components of household food security: food *quantity* available in the household, food *quality* as captured by dietary diversity and the presence of important nutrients, and the *stability* of adequate food supplies and also their analysis was based on four agro-ecological zones of Zambia in order to assess presence of food insecurity across agro-ecologies.

By using principal component analysis from the pooled data of the three waves, a multidimensional index for food security was built for Zambia which would help them to explore: spatial patterns of food security in the country across time, correlates of food insecurity and also to measure the impacts of climate shocks on food security. The result from their study shows that the two climatic variables: seasonal rainfall and temperature were having significant impact on a household's food security. Moreover, the study identifies the presence of differences in household food security status among agro-ecological locations of Zambia. However, the study did not explain the determinants of household food security in a disaggregated manner by using the entire analysis to be based on the agro-ecological zones of the country which would have helped to compare their results across agro-ecologies. Hence, they proposed future research to be done by using additional explanatory variables of food security as well as detailed data on each agro-ecological setting which would help to make comparison among determinants of food security.

2.2.4 Empirical Literature on Adaptation to Climate Change

There are a number of studies which address climate change adaptation across different parts of the world. The studies identified factors that determine farmers' perception about climate changes and shed light on determinants of choice of adaptation practices by the farmers.

Coretha and Edwin (2012) examined adaptation to climate change by smallholder farmers in the case of Tanzania based on a cross-sectional data from a sample of 556 randomly selected farm households. Their investigation was focused on identifying whether smallholder farmers of Tanzania recognize climate change and consequently use adaptation strategies to cope up with the changing environment. In addition to this, the research was also intended to determine factors that influence farmers' choice of climate change adaptation options in their agricultural farming practices.

But, the research failed to address the inter-dependent application of adaptations, i.e., they did not look at the adaptations as packages, rather they treat them individually. Binary logit and multinomial logit models were deployed to investigate factors that affect farmer's decision to use climate change adaptations in their farm plot and to identify possible factors which influence farmers' choice of specific adaptation measure respectively.

The results of the study show that smallholder farmers observe changes in the mean level of precipitation and temperature in the study area and they were responding to climatic changes by using drought-resistant crops, changing planting dates, irrigation, short season crops and planting trees to adapt the negative impacts of climate change in their farm plot. The result of their study also shows differences among the determinants of adaptations taken by farm households.

Among the studies which are undertaken in Ethiopia, the research by Deressa, Hassan and Ringler (2010) examined the perceptions of and adaptation to climate change by famers in the Nile Basin of Ethiopia using cross-sectional data from a sample of 1,000 households who were practicing mixed crop and livestock farming. The researchers were interested to examine the two-step process of adaptation to climate change: farmers' perceptions about climate change and the responses to the changes using climate change adaptation strategies. In order to make their analysis, they used Heckman Sample selection model to the two-step process of adaptation to climate change stated above. The result from their study reveals that the perception of the farmers to know whether climate change is happening or not was significantly related to the age of the household head, wealth, knowledge of climate change, social capital and agro-ecological settings. Unlike their expectations, those households who were living in Dega (highlands) perceived more changes in climate than those who live in Kola (lowland) or Woina dega (mid-land) agro-ecological settings.

According to the researchers, the reason for the deviations from their expectation might be, the recent drought which the households experience some years back in the study area or the environmental changes driven water scarcity in the Nile basin. Other factors such as education of the head of the household, household size, whether the head of the household was male, whether livestock were owned, the use of extension services on crop and livestock production, the availability of credit and the environmental temperature significantly affected farmers' adaptation to climate change in the study area. Male headed households were highly likely to adopt agricultural technologies than their female counter parts. They also find that the incidence of adaptation to climate change increases with an increase in temperature.

Moreover, they find a negative relationship between adaptation to climate change with that of farm size and they propose future research to account for farm characteristics which could reveal the determining factors that enforce households to take an adaptive measure at their farm or plot-level. The study also identified a negative relationship between the average annual precipitation and adaptation. The probable reason given by the researchers were an increase in the precipitation will have a counteracting effect on an increase in temperature in the area. Moreover, as the size of the household increases, the likelihood of climate change adaptation use also increased.

Di Falco *et al*.(2011a) examined the driving forces which leads a given farm household to use climate change adaptation strategies in order to overcome food productivity decline in the Nile basin of Ethiopia. Simultaneous equation model with endogenous switching was deployed in order to take into account the heterogeneity in the decision making whether to adopt or not. They also implemented a counter factual analysis between the adopters and non-adopters of climate change adaptation options to assess the possible differences of the two groups.

The results of their study indicates that access to credit, provision of climatic information and getting extension service are the main driving forces which affect farm households' decision to adopt in a changing environment. From their counter factual analysis, they found that those farm households who applied climate change adaptation strategies got increased food productivity than those who did not apply climate change adaptation strategies. But their study concentrated on food productivity side only and didn't include all food security components in their analysis.

Similarly, Di Falco *et al*.(2011b) assessed impact of climate change and adaptation strategies at household level in the Nile basin of Ethiopia by using production function and Ricardian approach.

The findings of the research reveals that age and education of the household head, household size, access to information and getting extension service were found to have a positive impact on households' adoption of climate change adaptation option to the changing environment. Moreover, the study explained that farm households who applied changing crops, soil conservation and tree planting as their adaptation strategies to the ever changing climate in the study area got a higher food productivity than that of their counterparts.

Teklewold *et al*.(2015) investigated adoption and impacts of combinations of cropping system intensification practices, cropping system diversification, conservation and modern varieties using nationally representative panel farm household survey data collected in 2010 and 2013 in Ethiopia. They apply multinomial endogenous switching regression in an impact evaluation framework to control for selection bias caused by observed and unobserved heterogeneities. The results show that conservation tillage, cropping system diversification, and modern varieties increase household income when they are adopted individually as well as in combination. However, the impact is greater when they are adopted in combination. They found ‘win-win’ outcomes - the highest payoffs and the lowest applications of agro-chemicals - when all these intensification practices are adopted jointly.

We can see from the results of the analysis their main focus was to investigate the income gain from adoption of individual and combinations of adaptations and the level of application of agro-chemicals.

Kassie *et al*.(2012) examined the adoption decisions for adaptation practices, using primary data of multiple plot-level observations collected in 4 districts and 60 villages of rural Tanzania. They applied a multivariate probit technique to model simultaneous interdependent adoption decisions by farm households. The result of their analysis reveals that rainfall, insects and disease shocks, government effectiveness in provision of extension services, tenure status of plot, social capital, plot location and size, household asset holding, all influence farmers investment in adaptation strategies to the changing environment. The study concentrated on the identification of determinants of adaptation and it doesn't explain their effect on the food security status of farm households in the study area.

Based on theoretical and empirical reviews that have been done so far, this study identified and tried to address the following research gaps. There is lack of empirical literature which addresses the determinants of selection decisions to adopt individual and/or combinations of adaptations to attain food security (food security indexed using four components namely: availability, accessibility, stability and utilization) over a wide range of geographical setting. Almost all of the existing studies we are aware of did not consider the multidimensional aspects of food security using the four pillars (availability, accessibility, stability and utilization) together with packages (combinations) of adaptations to analyze the food security status of farm households. Thus to our knowledge there is no single work which uses the four pillars of food security in analyzing the effectiveness and pay-offs from applications of individual and/or combinations of adaptation strategies and also within different adaptation adoption to attain food security by farm households under different agro-ecological conditions using panel data. Hence, the current study tries to fill those gaps.

CHAPTER THREE: METHODOLOGY

3.1 Description of the Study Area

The study is conducted in the Nile Basin of Ethiopia which is one of the areas hit hard by consecutive drought, flood and natural hazards for so many years and also an area which is more susceptible to climate change driven abnormalities. Nile Basin of Ethiopia covers a total area of about 358,889 Km^{2}which is equivalent to 34% of the total geographic area of Ethiopia and covers Amhara, Oromiya, Benishangul-Gumz, Tigray, Gambella and Southern Nations Nationalities and Peoples regional states of Ethiopia with a proportion of 38%, 24%, 15%, 11%, 7% and, 5% of their total areas respectively (MoWR, 1998). In the Nile basin of Ethiopia, there are three major rivers which originate from different locations within the basin namely: Abbay River, originating from the central highlands; Tekeze River, originating from the north-western parts of the country and Baro-Akobo River originating from the south-western part of the country.

Figure 3.1:GPS Point Locations of the Sample Sites in the Nile Basin of Ethiopia

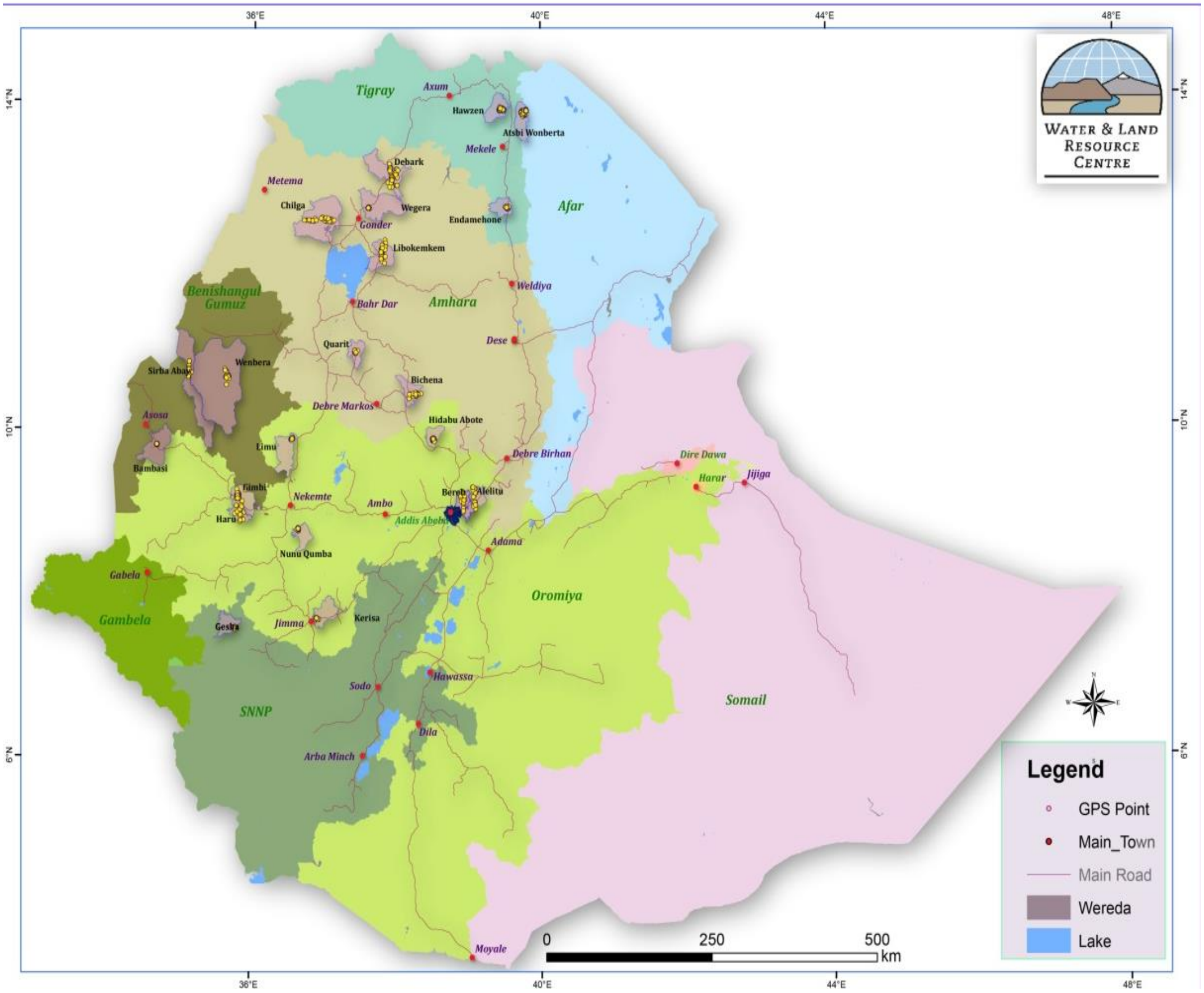
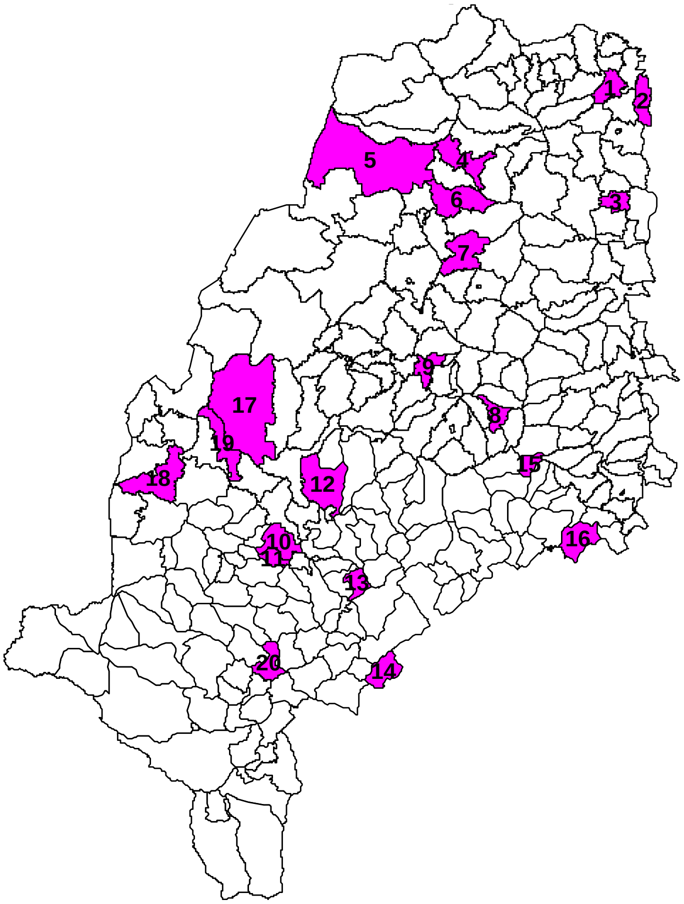


Figure 3.2:Map of Woredas Selected for the Samples in Nile Basin of Ethiopia



Legend: Key to woredas (districts) in sample for map in Figure 3.2.

No.	**District (Woreda)**
1	..........Hawzen
2	..........AtsbiWenberta
3	...........Endamehoni
4	...........Debark
5	...........Sanja
6	...........Wegera
7	...........Kemkem
8	...........Enemay
9	...........Quarit
10	.... Gimbi
11	..........Haru
12	..........Limu
13	..........NunuKumba
14	.... Kersa
15	.... HidabuAbote
16	.... BerehAleltu
17	.... Wembera
18	.... Bambasi
19	.... SirbaAbay
20	.... GeshaDaka

The farming practice in the study area is characterized by small-holder subsistence farming. Like many parts of Ethiopia, farming system in the Nile Basin of Ethiopia is very much traditional where farmers plough and use animal draught power to undertake their agricultural practices (Yesuf *et al*. 2008).

Moreover, the region is highly exposed to extreme weather and climatic variations such as drought, flood and erratic rainfall for so many years which resulted in food insecurity and lack of water (Di Falco *et al.*2011).

3.2 Nature and Method of Data Collection

To address the food security issues and the specified gaps in the literature discussed above, primary data is collected for the year 2015/16 by incorporating questions on food security status of households currently (2015/16) as well as their previous status in 2014/15 (using recall questions)to those previously sampled (2014/15) and interviewed agricultural households by the Environment and Climate Research Center at the Ethiopian Development Research Institute. The study used panel data of 909 farm households for the two rounds of the survey from Nile Basin of Ethiopia. The data include household and climatic characteristics, different climate change adaptations undertaken by farm households at their plot level and food security status of the households in the Nile Basin of Ethiopia for the two-waves.

To undertake the study, primary data collected from the selected farm households using structured questionnaires and secondary data of climatic variables such as yearly rainfall and temperature data(accessed from National Meteorological Agency of Ethiopia) was used.

3.3 Sampling Frame and Techniques

The sampling frame of this research is the Nile Basin of Ethiopia which consists of six regional states that are included in the basin: Amhara, Oromiya, Benishangul-Gumz, Tigray, Gambella and Southern Nations Nationalities and Peoples regional states.

In those regional states which are included in the Nile Basin of Ethiopia, the sampling was done based on the traditional typology of agro-ecological zones of the country (namely: Dega,Woina Dega, Kolla and Berha), percent of cultivated land, level of households food security, average annual rainfall, rainfall variability, climate change adaptation options and vulnerability (number of food aid dependent population) at which the frame was developed to select sample districts purposely.

The sampling frame selected woredas (an administrative division equivalent to a district) in such a way that each class in the sample matched to the proportions for each class in the entire Nile basin. The procedure resulted in the inclusion of twenty woredas. Random sampling was then used in selecting one village from each woreda and fifty households from each village.

3.4 Method of data Analysis

After collecting all the necessary primary and secondary data for our analysis, Principal Component Analysis method is used to generate multidimensional household food security index for each household by using different indicators of food security. This index is used to segregate households in to two mutually exclusive groups: food secure and food insecure households.

Empirical analysis was done by employing a multinomial logit model in order to investigate household's plot level determinants of selection decisions to adopt individual and/or combinations of adaptation strategies to climate change. Following the methodology used by Kassie *et al*.(2015), a multinomial endogenous switching regression model with fixed effects is applied to investigate how adoption of individual and/or combinations of climate change adaptation practices impact on farm household food Security[4].

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[4] Food Security Index is derived from the four Food Security Components (i.e. Availability, Accessibility, Utilization and Stability).

3.4.1 Principal Component Analysis

In order to build household level food security index which is comparable over time, Principal Component Analysis (PCA) method is employed. Principal Component Analysis is a type of factor analysis that can reduce dimensions or uncover latent variables by extracting linear combinations that best describe the co-variance among all elements (Abeyasekara *et al*.2005). The selection of indicators for this research is based on previous literature (Abera *et al*.2011; Ginbo 2014).

Since all four components of food security: availability, accessibility, utilization and stability do not have equal contribution for the attainment of food security, the indicators are ranked by giving unequal weight. To avoid subjectivity on giving ranks for the food security indicators, Principal Component Analysis (PCA) method is used.

As this study uses two waves of household panel data, it is necessary to generate an index that is comparable over time and see how this food security index behaves through time. Data for the two rounds of the survey is combined and principal components are estimated based on the combined data as described by Cavatassi *et al*.(2004). The weights found from the principal component analysis are then applied to the household level data for each of the two rounds of the survey. Once the first component is identified, it is possible to derive the food security index of each household using the values of each indicator as well as the weights, mean and standard deviation of the indicators for all selected farm households in the two periods separately. Then, the food security index can be calculated as:

$$\mathrm{FSI_j} = \sum W_i \left[\frac{X_{ji}-M_i}{S_i}\right] \qquad (1)$$

Where: FSI_j= Food security index for j^{th} household possessing standard normal distribution.

W_i= weight attached to i^{th} indicator variable in the PCA model.

X_{ji}= the j^{th} household value for i^{th} variable.

M_i= mean value of i^{th} variable for overall households in the sample.

S_i= standard deviation of i^{th} variable for overall households in the sample.

The household food security index segregates the households into two groups: food secure and food insecure groups for the two periods (2014/15,2015/16):households with negative index are characterized as food-insecure whereas households with a positive index are considered food secure. This index is used as a dependent variable to investigate the effect of applications of individual and/or combinations of climate change adaptation strategies at plot-level in helping to ensure food security of farm households.

3.4.2 Endogenous Switching Regression Econometric Framework

In this study we followed the methodology used by Kassie *et al*.(2015): a multinomial endogenous switching regression model with fixed effects to account for how adoption of individual as well as alternative combination of climate change adaptation practices impacts on farm household Food Security. There are several issues to be addressed in the econometric strategy to investigate the role of a combination of climate change adaptation strategies on various farm outcomes (in this case the outcome is food security status of farm households). Adoption of a combination of adaptation practices may not be random, but farmers endogenously self-select themselves into adoption/non-adoption decisions, so decisions are likely to be influenced by unobservable characteristics that may be correlated with the outcomes of interest.

This is a sample selection bias problem which leads to inconsistent estimators. Hence, it requires employing a selection correction method – computing an inverse Mills ratio using the theory of truncated normal distribution (Lee 2005; Bourguignon et al. 2007). The inverse Mill's ratios calculated from the multinomial logit models are then added as additional regressors to the outcome equations of food security in order to reduce the bias from not accounting for selection into the adoption decisions. In the second step we applied fixed effect regression model in our Food Security Index estimation.

Following Lee (1983), Dubin and McFadden (1984), Dustmann and Rochina-Barrachina (2007), and Wooldridge (2010) the underlying decision process of applications of improved varieties, crop rotation and inorganic fertilizer is explicitly modeled using a multinomial logit model to deal with these sample selection issues. It is assumed that crop rotation, improved varieties and application of inorganic fertilizer are jointly determined in a multinomial selection process. To illustrate this multinomial selection process, our sample is partitioned according to eight mutually exclusive combinations of crop rotation, improved varieties and applications of inorganic fertilizer in order to improve the food security index of farm households.

Let y_{it}represent a choice variable that assumes the values 1, 2, . . . , 8 corresponding to the eight combination of climate change adaptation practice regimes. We can equivalently define indicator variables corresponding to these eight regimes: y_{it} = 1[y_{it}= j] . Following Wooldridge (2010; pp 653-654), we specify that $p(y_{it} = j|x_{it}, \varepsilon_{it})$ = p(y_{it} = j|x_i,ε_i) , j = 1, 2, . . . , 8 is determined according to a multinomial logit model with unobserved individual effects:

$$\mathrm{p}(y_{it} = \mathrm{j}|x_i,\varepsilon_i) = \frac{exp\left(X_i\beta_j\right)}{\sum_{m=1}^{j} exp\left(X_i\beta_j\right)} \qquad (2)$$

where $x_{it}$is a vector of observed exogenous variables (household and plot characteristics) in the model for which there are observations for $\forall i$ and t , x_i is the vector of all observation for $x_{it}$for the ith individual with the associated parameter of coefficient β_j and ε_i is unobserved heterogeneity. The model is then estimated by a maximum likelihood function (Green 2003).

In the first stage of our panel data estimation of the endogenous switching regression model, we estimate a pooled multinomial logit model to capture the correlations between regressors and individual effects. From these estimation results we derive the appropriate Inverse Mills Ratio (IMR) variables that will be added as additional explanatory variables in the second stage outcome equations.

The assumed multinomial selection model generates probabilities according to:

$$P_{itj} = p(y_{it} = j|x_{it}) , \quad j = 2,...8$$

where β_j is the multinomial logit parameter vector for outcome j .

Therefore, the Inverse Mill’s Ratio (λ_{itj}) is defined as the ratio between the standard normal probability distribution function and the standard normal cumulative distribution function evaluated at each $x_{it}\beta$ for y_{itj}.

3.4.2.1 Outcome equations of Endogenous Switching Regression

To determine the impact of combination of crop rotation, improved varieties and application of inorganic fertilizer on the outcome variable (Food Security Index), the relationship between the outcome variables and a set of exogenous variables Z (plot, household characteristics) is estimated by fixed effect model for the chosen package. In our packages of climate change adaptation practices applications the reference category, i.e., non-adoption of practices ($I_0C_0F_0$) is denoted j=1.

At least one climate change adaptation practice is used in the remaining packages (j=2, . . .,8). The outcome equation for each possible regime is given as: j

$$\begin{cases} \text{Regime 1}: Q_{it1} = Z_{it}\alpha_1 + U_{it1} & \text{if } Y_{it} = 1 \\ . \\ . \\ \text{Regime J}: Q_{itJ} = Z_{it}\alpha_J + U_{itJ} & \text{if } Y_{it} = J \end{cases} \qquad (3)$$

where Q_{it}'s are the outcome variables of the i^{th} farmer in regime j at time t and the error terms (U_{itj}'s) are distributed with $E(U_{itj} |\, X, Z) = 0$ and Var $(U_{itj} | X, Z) = \sigma_j^2$.

Q_{itj} is observed if and only if package j is used. The error term U_i consists of unobservable individual effects c_i and a random error term e_{it}. If ε's and u's are not independent, the OLS estimates in (3) will be biased. A consistent estimation of α_j requires inclusion of the selection correction terms of the alternative choices in (3).

In the multinomial choice setting, there are J-1 selection correction terms, one for each alternative package. The second stage equation of the multinomial endogenous switching regression in (3) is re-specified as:

$$\begin{cases} \text{Regime 1}: Q_{it1} = Z_{it}\alpha_1 + \sigma_1\hat{\lambda}_{it1} + U_{it1} & \text{if } Y_{it} = 1 \\ . \\ . \\ \text{Regime J}: Q_{itJ} = Z_{it}\alpha_j + \sigma_J\hat{\lambda}_{itJ} + U_{itJ} & \text{if } Y_{it} = J \end{cases} \qquad (4)$$

whereσ_J is the parameter of coefficients for$\hat{\lambda}_{itJ}$ showing the covariance between ε's and u's. To control for potential omitted variable bias caused by the error termU_i , being correlated with the explanatory variables, a fixed effect model is estimated. Estimated standard errors in (4) are bootstrapped to account for the bias in the standard errors caused by the generated regressors due to the two stage estimation procedure.

A necessary identification restriction for the multinomial selection framework is that at least one of the explanatory variables included in the multinomial logit equation is excluded from the outcome equation (Billari and Borgoni, 2005). The reason for this exclusion restriction is that the inverse Mill’s ratio is a non-linear function of the explanatory variables in the multinomial logit equation; thus, the second stage equation (i.e. Food Security Index equation) is identified because of this non-linearity.

However, the non-linearity of the inverse Mill’s ratio is not normally tested or justified. Therefore, in order to make the source of identification clear, it is advisable to have an explanatory variable in the multinomial logit equation, which is not included in the second stage outcome equation (Greene, 2003). The explanatory variables that are only included in the multinomial logit specification to meet this exclusion restriction are farm households membership of agricultural cooperatives, household have access to watershed management groups, met extension agents on agricultural activities, farm household got climatic information from any sources (i.e., climatic information from their neighbor, climatic information from media (television and radio), climatic information from agricultural extension offices) and farm household contacted extension agents on household members health and sanitation. It is assumed that these variables influence adoption of packages of climate change adaptation practices and have no direct effect on food security index except through adoption.

We checked their validity and a test result shows that nearly in all cases the variables are jointly significant in the adoption equations but not in the food security equations.

3.4.2.2 Estimation of Average Treatment Effects

From the econometric approach outlined above there are several quantities that we may be interested in. The estimates that are most commonly of interest are the average treatment effect on the population (ATE), the average treatment effect on the treated (ATT), and the average treatment effect on the untreated (ATU). The ATE is the unconditional average adoption effect which answers the question of how, on average, the Food Security Index would change if everyone in the population of interest had been assigned to a particular or combinations of climate change adaptation practices relative to a situation where they had all received none of the practices.

The ATT and ATU answers the question of how the average outcome variable (food security index) would change if everyone who received one particular treatment had not received any treatment.

The ATE of package (j) versus package (2) is defined in equation (3) as:

$$\text{ATE} = E(Q_{itj} - Q_{it1} | Z = Z_{it}) = Z_{it} (\alpha_j - \alpha_1) \quad \text{for } j = 2,.....8 \qquad (5)$$

In observational studies where the investigators have no control over the assignment of individual and/or packages of climate change adaptation practices, the adoption status is likely to be dependent on outcomes and thus a biased estimator of the ATE. However, the ATT and ATU is used to compare expected Food Security Index of adopters and non-adopters with the counterfactual hypothetical case that adopters did not adopt and vice versa, respectively.

Following Carter and Milon (2005) and Di Falco *et al*.(2011), the expected Food Security Index under the actual and counterfactual hypothetical cases are computed as follows, by applying equations (4).

Adopters with adoption (actual): $E[Q_{itj}|Y_{it} = j] = Z_{itj}\alpha_j + \sigma_j\lambda_{itj}$ (6)

Non-adopters without adoption (actual): $E[Q_{it1}|Y_{it} = 1] = Z_{it1}\alpha_1 + \sigma_1\lambda_{it1}$ (7)

Adopters had they decided not to adopt (counterfactual): $E[Q_{it1}|Y_{it} = j] = Z_{itj}\alpha_1 + \sigma_1\lambda_{itj}$ (8)

Non-adopters had they decided to adopt (counterfactual): $E[Q_{itj}|Y_{it} = 1] = Z_{itj}\alpha_j + \sigma_j\lambda_{it1}$ (9)

Equations (6) and (7) represent the expected outcomes of adopters and non-adopters that were actually observed in the sample, whereas equations (8) and (9) denote the counterfactual expected outcomes of adopters and non-adopters, respectively. These expected values are used to compute unbiased estimates of the effects of adoption on adopters and on non-adopters.

The average climate change adaptation practices adoption effect on the adopters (ATT) is defined as the difference between equations (6) and (7):

$$\text{ATT} = E[Q_{itj}|Y_{it} = j] - E[Q_{it1}|Y_{it} = 1] = Z_{it}(\alpha_j - \alpha_1) + \lambda_{itj}(\sigma_j - \sigma_1) \quad (10)$$

Similarly, the average effects of adoption of different climate change adaptation practices on non-adopters (ATU), i.e., the effects of adoption on those who do not adopt if they did adopt, is computed as the difference between equations (8) and (9):

$$\text{ATU} = E[Q_{itj}|Y_{it} = 1] - E[Q_{it1}|Y_{it} = j] = Z_{it}(\alpha_j - \alpha_1) + \lambda_{it1}(\sigma_j - \sigma_1) \quad (11)$$

The ATT and ATU parameters give the expected outcome effect of adoption, controlling for selection bias on a randomly chosen household from the groups who adopt and do not adopt combination of different climate change adaptation practices, respectively.

The effects of adoption are likely to be heterogeneous: adopters and non-adopters may not benefit in the same way from adoption even if they have the same observed characteristics due to other endogenous determinants of the outcome variables. This can be tested by taking the difference between equations (10) and (11).

3.4.3. Description of Explanatory Variables and prior expectation

A set of socioeconomic and environmental factors are included in the empirical models. Explanatory variables included in the study are household head characteristics such as age, sex, literacy, family size, marital status and dependency ratio, and plot characteristics such as, fertility index, slope index, and altitude of the plot, and farm size. Moreover, household total annual income earned including remittance, access to credit, climate shock, livestock, number of beehive, labor hours, rainfall, temperature, and co-operative involvement are also included. The dependent variables of this study are food security index and individual /combinations of climate change adaptation (i.e., applications of Improved Varieties, Crop Rotation and Inorganic Fertilizer). The description, type, value and expected sign (depending on previous literatures) are given in Table 3.4.3

Table 3.4.3 Description of explanatory variables and their expected sign

No.	Variable	Description and Variable type	Value	Expected Sign	
				Adoption	Food Security
1	**Household Characteristics**				
	Age	Age of the household head: Continuous	Years	-	-
	Gender	Sex of the head of the household: dummy	1 = Male, 0 = Female	+	+
	Marital Status	Marital Status of household head: dummy	1 = Married, 0 = Otherwise	+	+
	Literacy	Educational Status of household head	1 = Literate, 0 = Illiterate	+	+
	Household Size	Number of a members of the household: Continuous	Number	(±)	-
	Dependency Ratio[5]	Dependence ratio can be calculated as the ratio of the number of household members non-participated in farming practices to that of the participated members of the household: Continuous	Number		-
	Total annual income earned	Total annual income earned from non-own farm or non-farm employments, non-farm business including remittance: Continuous	Number	+	+
2	**Climatic factors**				
	Temperature	Average temperature (°C) 1983-2015: Continuous	Number	+	-
	Rainfall	Average amount of annual rainfall in (mm) 1983-2015: Continuous	Number	+	-
	Climate Information from any source	If the farm household gets climatic information from any source: dummy	1 = Yes, 0 = Otherwise	+	+
	Climatic Information from extension officers	If the farm household gets climatic information from extension officers: dummy	1 = Yes, 0 = Otherwise	+	+
	Climatic Information from its neighbor	If the farm household gets climatic information from its neighbor: dummy	1 = Yes, 0 = Otherwise	+	+
	Climatic Information from media(radio &	If the farm household gets climatic information from media(radio & television): dummy	1 = Yes, 0 = Otherwise	+	+
3	**Plot Characteristics**				
	Fertility Index[6]	Index of the fertility of the plot: Continuous	Number		+
	Altitude	Altitude of the plot: Continuous	Number		+

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[5] Dependency ratio is calculated by dividing the number of economically inactive(those household members aged below 15 and above 65) to active or productive members (those aged between 15 and 65).

[6] Fertility index is calculated by using farmers perception of their farm plots as highly fertile, moderately fertile and infertile by giving 1,2 and 3 to their results respectively and the dividing it by three.

	Slope Index[7]	Index of the slope of the plot: Continuous	Number	+	-
	Shock Index[8]	Index of previous climatic shocks: Continuous	Number	+	-
4	**Institutional Factors**				
	Land Certification	If the farm plot is certified: dummy	1 = Yes, 0 = Otherwise	+	+
	Credit	If the farm household have access to credit service: dummy	1 = Yes, 0 = Otherwise	+	+
	Watershed management	If the farm household have access to watershed management group: dummy	1 = Yes, 0 = Otherwise	+	+
	Health extension	If the farm household have met an extension agent in health related issues: dummy	1 = Yes, 0 = Otherwise	+	+
	Agricultural extension	If the farm household have met an extension agent in agriculture related issues: dummy	1 = Yes, 0 = Otherwise	+	+
	Cooperative membership	If the farm household is a member of agricultural cooperatives: dummy	1 = Yes, 0 = Otherwise	+	+
	Market distance to sell outputs	Average minutes taken between farmer's house and the nearest market to sell their outputs: Continuous	Minutes	-	-
	Market distance to buy/get inputs	Average minutes taken between farmer's house and the nearest market to get inputs: Continuous	Minutes	+	+
5	**Assets**				
	Size of farm land	Size of cultivated farm land per hectare held by household: Continuous	Hectare	(±)	+
	TLU[9]	Tropical Livestock Unit owned by farm household: Continuous	Weight		+
	Number of Beehive	The total number of beehive farm household owns: Continuous	Number		(±)
6	**Inputs**				
	Labor hours	Total labor hour spent per hectare of cultivated land both own and paid labor: Continuous	Number	+	+
	Organic fertilizer	Amount of manure and compost used per hectare: Continuous	Kilogram		+

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[7] Slope index is calculated by using farmers perception of their farm plot setting as flat, slightly incline and steep by giving 1,2 and 3 to their results respectively and the dividing it by three.

[8] Shock index is calculated by dividing shocks that happened previously/a year before in their farm plot to the seven shocks which are given to farmers as an alternative to the answer whether it happened or not in their farms. The seven shock are: drought, flood, erratic rainfall pattern, animal attack, landslide, hailstorms and other climatic shock specified by the respondents.

[9] TLU (Tropical Livestock Unit) describes livestock numbers of different species and types as a single figure which express the total amount of livestock owned by the farm household without making to consideration of their types.

CHAPTER FOUR: RESULTS AND DISCUSSIONS

In this section both descriptive and econometric results are presented and discussed. In the first section, results of descriptive analysis of the study are presented and discussed. In the second section, results of application of the econometric model used are presented and discussed.

4.1 Descriptive Analysis

The demographic characteristics and socioeconomic variables of sampled households for the two rounds of the survey (2014/15 and 2015/16) were relevant in providing some information about the general features of the area under examination. Therefore, different socioeconomic and demographic characteristics of farm household such as: age, sex, marital status and literacy of household head, household size, dependency ratio and total annual income earned (including remittance) are included in this section.

The mean values of those stated variables are presented in Table 4.1.1 a,b for the total, adopters and the non-adopters of climate change adaptation strategies using the two rounds of survey data separately. Analysis of adoption of the three climate change adaptation practices (crop rotation, improved varieties and application of inorganic fertilizer) leads to eight combinations[10] of choices from which the farmer is able to choose.

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[10] Adopters are divided in to seven groups: Inorganic Fertilizer ($I_0C_0F_1$); Crop rotation ($I_0C_1F_0$); Improved Varieties ($I_1C_0F_0$); Improved Varieties and Crop rotation ($I_1C_1F_0$); Improved Varieties and Inorganic Fertilizer ($I_1C_0F_1$); Crop rotation and Inorganic Fertilizer ($I_0C_1F_1$) and lastly Improved Varieties, Crop rotation and Inorganic Fertilizer ($I_1C_1F_1$) adopters.

The statistics indicates that average household size for the sample household were around 6.627 for the whole sample of adopters (both single and package adopters), 6.608 for single climate change adaptation ($I_0C_0F_1$,$I_0C_1F_0$ and $I_1C_0F_0$) adopters and 6.641 for different combinations of climate change adaptation adopters ($I_1C_1F_0$,$I_1C_0F_1$,$I_0C_1F_1$,$I_1C_1F_1$) respectively.

On the other hand the average household size for the non-adopters ($I_0C_0F_0$) is 6.325. Average household size of those farm households who adopt more than one climate change adaptation (packages of adaptations) is slightly higher than those who adopt single ones. Household size is also lower for those who do not adopt any of the adaptation practices at all as compared to adopters of single adaptation practice as well as adopters of combinations of practices. This suggests that having relatively increased household size leads to have greater advantage of increased labor for agricultural practices and for application of climate change adaptation strategies. This is consistent with the result found by Deressa *et al*. (2010).

Among the sample respondents, on average 85.5 percent of household heads who did not apply any of the adaptation strategies were male. In comparison, on average 88.8 and 89.6 percent of those households who applied a single adaptation strategy and combinations of adaptations were headed by male household heads respectively. This shows a slight increase in the adoption rate for the male headed adopter households when it is compared with non-adopters. This is also consistent with the findings of the study by Deressa *et al*. (2010) where male headed households were found to be highly likely to adopt agricultural technologies than their female counterparts. The proportion of mean married and male headed farm households is found a little bit higher for the group of adopters (both single and package adopters) compared with non-adopters.

The average total annual income earned (including remittance) for adopters (both single and packages) farm households is3,105 birr. On the other hand the average annual household income for single adoption adopters is 2,170 birr which is relatively much lower than those households who adopt climate change adaptation strategies as packages, which is 3,806 birr. This suggests, on average, the likelihood of adopting combinations of climate change adaptation strategies is found higher for farm households who earn more annual income than those who earn lower annual income.

The dependency ratio which is calculated by dividing the number of economically inactive members (household members aged below 15 and above 65) to active or productive members (aged between 15 and 65) of farm household are 0.790, 0.910 and 0.813 for non-adopters, individual practice adopters and adopters of combination (Packages) of practices respectively.

Interestingly, the food security index which is calculated by using the four food security components show that non-adopter households are highly vulnerable to food insecurity problem than households who applied single adaptations as well as packages of adaptation adopters. On average -0.080, 0.023 and 0.214 are the food security index of non-adopters, individual adaptation adopters and packages adaptation adopters respectively. The results of descriptive analysis of food security index also show that adopters of a combination of practices are away from food insecurity problem than both individual adoption adopters and non-adopters.

4.1.1 Plot Characteristics

Plot level characteristics considered in this study include plot fertility index, shock index, slope index and land certification. A total of 6064 plots in 2014/15 and 5920 plots in 2015/16 of 909 farm households are included in the study.

Soil fertility of plots were placed on three levels based on farmers' perception about their plots and divided into three levels (highly fertile, moderately fertile and infertile soil). The fertility index goes from 0 to 1; as the fertility index gets close to 1 it means highly fertile plot than the plot where the fertility index approaches 0. On average 0.616, 0.609 and 0.583 are the soil fertility index for non-adopters, individual adaptation adopters and packages adaptation adopters respectively.

Similarly, the shock index is calculated by using the questions that are asked to the farm household about their past experience of shocks in their farm plots. Seven shocks were asked for sampled household by saying which shocks were faced in the past and on which plot the shocks happened. Then, shock index is computed by dividing the number of shocks happened in a plot to the total shocks which are expected to face farmers. The shock index goes from 0 to 1 and as the shock index nears to one it means more shocks happened in that plot than the plot where the shock index approaches to 0.On average 0.069, 0.105 and 0.114 are the shock index for non-adopters, individual adaptation adopters and packages adaptation adopters respectively.

Slope of the plots were placed on three levels based on farmers' perception about their farm plots and it is divided into three levels (flat slope, slightly inclined slope and steep slope). Slope index is computed by dividing the attached level by three. On average 0.514, 0.495 and 0.114 are the slope index for non-adopters, individual adaptation adopters and packages adaptation adopters respectively. Households were also asked whether the plots are certified or not. Eighty five percent of the non-adopter farm plots were certified. On the other hand, 80% and 85% of farm land for those who adopt a single adaptation and a combination(packages) of adaptation were certified.

4.1.2 Institutional Factors, Asset holdings and Climate Change Adaptations

About85 percent of the total sample households in the two rounds of the survey have access to credit while 56 percent of them were members of agricultural cooperatives; and 37 percent of them have access to watershed management groups in their vicinity. Being part of agricultural cooperatives and having access to watershed management groups are expected to have positive exposure for farmers to have adoption related information and it can also make the accessibility of inputs used easier for adoption which is often distributed through cooperatives.

Access to credit could help improve farm households' access to new production technology. In our case, this refers to application of the three combinations of climate change adaptation technologies (Crop rotation, Inorganic Fertilizer and Improved Varieties) to their farm plots. We see from the descriptive statistics that on average access to credit for those farm households who adopt combinations of adaptations is higher than to that of non- adopters and also individual adaptation strategies adopters.

The average time (in walking minutes) for farm households to reach the nearest market where they can sell their outputs is taken as a proxy of market access to sell their outputs. The descriptive statistics shows that on average the nearest market to sell their outputs takes a walking time of around 62, 65 and 59 minutes for non-adopters, individual adaptation adopters and combination (Package) adopters respectively. On average, the walking time taken to the nearest market to sell outputs is slightly lower for combination (package) adopters than single adaptation adopters and also for non-adopters. On the other hand, the average time (in walking minutes) for farm households to reach the nearest market where they can buy inputs to their farming practice is taken as a proxy of market access to get inputs.

The results shows that on average the nearest market to get input takes a walking time of around 48, 54 and 51 minutes for non-adopters, individual adaptation adopters and combination (Package) adopters respectively.

Ownership of livestock is determined using tropical livestock unit (TLU) in order to have a uniform measurement for all types of livestock. The mean livestock unit for adopter (both single and packages) farm households were found to be 4.912 whereas it is 4.900 for the non-adopters. The mean livestock ownership for households who adopt packages of adaptation strategies ($I_1C_1F_0$,$I_1C_0F_1$,$I_0C_1F_1$,$I_1C_1F_1$) is found to be 5.049, which is higher than that of the non-adopter and individual adaptation adopter ($I_0C_0F_1$,$I_0C_1F_0$ and $I_1C_0F_0$) farm households'.

Average land holding of farm households is found to be 1.85 hectare per household for the total sample, while it is 1.78 , 1.77 and 1.79 hectare for adopters (both single and packages of adoptions adopters), isolated adaptation and combinations of adaptation adopters respectively. On the other hand, non-adopters owned about 1.90 hectare of land in the study area.

As can be seen in Table 4.1.1a,b out of the total cereal crop planted plots in the Nile Basin of Ethiopia,36.16 percent of the total respondents are non-adopters ($I_0C_0F_0$) whereas, 4.18, 19.20, 0.45, 3.43, 1.39, 15.90 and 19.29 percent of the respondents are adopters of Inorganic Fertilizer ($I_0C_0F_1$), Crop rotation ($I_0C_1F_0$), Improved Varieties ($I_1C_0F_0$), Improved Varieties and Crop rotation ($I_1C_1F_0$), Improved Varieties and Inorganic Fertilizer ($I_1C_0F_1$), Crop rotation and Inorganic Fertilizer ($I_0C_1F_1$) and lastly Improved Varieties, Crop rotation and Inorganic Fertilizer ($I_1C_1F_1$) respectively.

Table 4.1.1a

Descriptive Statistics

			Mean Value of Adpters													
	Mean Value for Non-Adopters		Application of Inorganic Fertilizer		Crop Rortation		Improved Varaities		Improved Varities and Crop Rotation		Improved Varities and Fertilizer		Crop Rotation and Fertilizer		Improved Varities , Crop Rotation and Fertilizer	
	($I_0C_0F_0$)		($I_0C_0F_1$)		($I_0C_1F_0$)		($I_1C_0F_0$)		($I_1C_1F_0$)		($I_1C_0F_1$)		($I_0C_1F_1$)		($I_1C_1F_1$)	
VARIABLES	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16	2014/15	2015/16
Household Characteristics																
Age	51.280	52.320	52.210	51.460	52.090	53.230	48.840	51.760	49.670	54.970	51.870	50.160	53.570	53.840	52.270	52.530
Sex	0.860	0.850	0.850	0.920	0.870	0.910	0.880	0.900	0.870	0.880	0.910	0.950	0.870	0.880	0.900	0.910
Marital Status	0.840	0.790	0.780	0.880	0.800	0.860	0.760	0.900	0.830	0.850	0.900	0.850	0.820	0.820	0.860	0.830
Literacy	0.420	0.380	0.340	0.380	0.260	0.310	0.440	0.340	0.460	0.300	0.290	0.440	0.250	0.260	0.350	0.340
Household Size	6.380	6.270	6.300	6.690	6.650	6.590	6.280	7.140	6.410	6.560	7.210	6.380	6.620	6.380	6.760	6.810
Dependency Ratio	0.800	0.780	0.900	0.760	0.880	0.840	1.110	0.970	0.970	0.730	0.770	0.780	0.890	0.770	0.770	0.820
Total annual income earned (including remittance)	3300.710	3479.500	2156.670	2281.830	1829.560	3283.560	1676.800	1789.660	3469.510	3740.680	4852.840	3295.260	2053.110	3242.700	4641.890	5148.790
Food Security Index	-0.049	-0.111	0.118	0.095	-0.102	-0.011	-0.148	0.184	0.319	0.347	0.141	0.151	-0.067	0.023	0.389	0.411
Assets																
Size of farm land	1.900	1.890	1.700	1.650	1.750	1.770	1.890	1.870	1.780	1.770	1.670	1.770	1.770	1.760	1.890	1.880
TLU	5.170	4.630	4.860	4.890	4.580	4.540	5.180	4.330	5.190	4.860	5.410	4.920	5.060	4.720	5.240	4.990
Number of Beehive	1.720	1.090	1.240	1.350	1.740	0.820	1.600	0.520	2.710	1.520	1.640	0.420	0.770	0.780	1.610	1.170
Institutional Factors																
Land Certification	0.850	0.850	0.810	0.830	0.840	0.870	0.640	0.830	0.710	0.880	0.760	0.900	0.870	0.930	0.850	0.890
Acess to Credit	0.790	0.840	0.900	0.840	0.840	0.810	0.840	0.860	0.900	0.820	0.910	0.810	0.890	0.790	0.890	0.860
Access to Watershed Mang't Group	0.390	0.370	0.490	0.410	0.300	0.390	0.240	0.510	0.290	0.510	0.370	0.440	0.420	0.340	0.330	0.350
Access to Membership of Agricultural Cooperative Groups	0.553	0.621	0.538	0.607	0.456	0.599	0.480	0.621	0.461	0.575	0.582	0.650	0.454	0.620	0.499	0.600
Meet Extension agent on Health and Sanitation	0.940	0.890	0.950	0.930	0.930	0.870	0.960	1.000	0.900	0.860	0.960	0.880	0.950	0.870	0.930	0.880
Mk't distance to Sell Outputs in minutes	65.720	57.660	73.340	60.880	69.640	60.520	64.400	59.140	62.870	49.650	63.580	55.670	68.240	60.140	59.870	58.680
Mk't distance to get Inputs in minutes	49.320	45.760	54.740	53.970	56.810	48.870	60.200	46.340	54.260	40.690	50.450	48.080	60.690	52.790	50.010	49.500
Plot Characteristics																
Fertility_Index	0.621	0.612	0.624	0.617	0.589	0.607	0.642	0.576	0.576	0.569	0.598	0.601	0.570	0.589	0.568	0.589
Slope_Index	0.534	0.493	0.497	0.496	0.495	0.459	0.574	0.447	0.489	0.483	0.492	0.466	0.458	0.440	0.466	0.472
Shock_Index	0.063	0.075	0.162	0.091	0.140	0.083	0.108	0.044	0.120	0.076	0.152	0.066	0.152	0.119	0.137	0.091
Dega	0.300	0.351	0.285	0.402	0.525	0.514	0.080	0.310	0.298	0.608	0.164	0.270	0.416	0.458	0.432	0.396
Woinadega	0.652	0.587	0.708	0.571	0.383	0.385	0.560	0.414	0.481	0.294	0.731	0.670	0.575	0.579	0.514	0.560
Kolla	0.040	0.064	0.007	0.031	0.003	0.101	0.360	0.275	0.221	0.098	0.104	0.006	0.009	0.014	0.054	0.044
Altitude	2136.130	2160.490	2178.670	2217.700	2313.240	2279.070	1828.800	2014.350	2017.620	2391.070	2029.600	2129.620	2266.750	2282.420	2243.190	2241.770
Inputs																
Labor_Hours per day	2.812	25.026	9.007	53.060	6.907	46.190	5.310	86.530	6.130	51.610	8.042	52.060	10.040	59.630	9.730	49.420
Amount of Manure and Compost per hectare	39.050	33.497	79.360	82.140	96.290	122.170	264.000	136.200	128.520	130.750	189.550	206.150	89.260	86.070	111.420	148.590
Percentage of Adopters for each year	31.84	40.57	4.57	3.78	20.02	18.36	0.41	0.49	4.25	2.58	1.10	1.69	17.00	14.76	20.79	17.75
Percentage of Adopters for the two years jointly	36.16		4.18		19.20		0.45		3.46		1.39		15.90		19.29	

Table 4.1.1 b

Descriptive Statistics

	Total Sample		Average for all groups of adopters			Average for Non-adopters			Average for Individual Adoption adopters			Average for Combinations Adoptions adopters		
VARIABLES	**2014/15**	**2015/16**	2014/15	2015/16	Total	2014/15	2015/16	Total	2014/15	2015/16	Total	2014/15	2015/16	Total
Household Characteristics														
Age	52.010	52.740	51.503	52.564	52.034	51.280	52.320	51.800	51.047	52.150	51.598	51.845	52.875	52.360
Sex	0.870	0.880	0.879	0.907	0.893	0.860	0.850	0.855	0.867	0.910	0.888	0.888	0.905	0.896
Marital Status	0.820	0.820	0.821	0.856	0.839	0.840	0.790	0.815	0.780	0.880	0.830	0.853	0.838	0.845
Literacy	0.340	0.340	0.341	0.339	0.340	0.420	0.380	0.400	0.347	0.343	0.345	0.338	0.335	0.336
Household Size	6.560	6.470	6.604	6.650	6.627	6.380	6.270	6.325	6.410	6.807	6.608	6.750	6.533	6.641
Dependency Ratio	0.840	0.800	0.899	0.810	0.854	0.800	0.780	0.790	0.963	0.857	0.910	0.850	0.775	0.813
Total annual income earned (including remittance)	3407.900	3654.960	2954.340	3254.640	3104.490	3300.710	3479.500	3390.105	1887.677	2451.683	2169.680	3754.338	3856.858	3805.598
Food Security Index	0.043	0.018	0.093	0.171	0.132	-0.049	-0.111	-0.080	-0.044	0.089	0.023	0.196	0.233	0.214
Assets														
Size of farm land	1.850	1.860	1.779	1.781	1.780	1.900	1.890	1.895	1.780	1.763	1.772	1.778	1.795	1.786
TLU	5.040	4.710	5.074	4.750	4.912	5.170	4.630	4.900	4.873	4.587	4.730	5.225	4.873	5.049
Number of Beehive	1.560	1.020	1.616	0.940	1.278	1.720	1.090	1.405	1.527	0.897	1.212	1.683	0.973	1.328
Institutional Factors														
Land Certification	0.840	0.880	0.783	0.876	0.829	0.850	0.850	0.850	0.763	0.843	0.803	0.798	0.900	0.849
Acess to Credit	0.880	0.830	0.881	0.827	0.854	0.790	0.840	0.815	0.860	0.837	0.848	0.898	0.820	0.859
Access to Watershed Mang't Group	0.360	0.370	0.349	0.421	0.385	0.390	0.370	0.380	0.343	0.437	0.390	0.353	0.410	0.381
Access to Membership of Agricultural Cooperative Groups	0.501	0.612	0.496	0.610	0.553	0.553	0.621	0.587	0.491	0.609	0.550	0.499	0.611	0.555
Meet Extension agent on Health and Sanitation	0.940	0.880	0.940	0.899	0.919	0.940	0.890	0.915	0.947	0.933	0.940	0.935	0.873	0.904
Mk't distance to Sell Outputs in minutes	65.910	58.620	65.991	57.811	61.901	65.720	57.660	61.690	69.127	60.180	64.653	63.640	56.035	59.838
Mk't distance to get Inputs in minutes	53.410	48.250	55.309	48.606	51.957	49.320	45.760	47.540	57.250	49.727	53.488	53.853	47.765	50.809
Plot Characteristics														
Fertility_Index	0.593	0.602	0.595	0.593	0.594	0.621	0.612	0.616	0.618	0.600	0.609	0.578	0.587	0.583
Slope_Index	0.495	0.475	0.496	0.466	0.481	0.534	0.493	0.514	0.522	0.467	0.495	0.476	0.465	0.471
Shock_Index	0.117	0.087	0.139	0.081	0.110	0.063	0.075	0.069	0.137	0.073	0.105	0.140	0.088	0.114
Dega	0.389	0.411	0.314	0.423	0.368	0.300	0.351	0.326	0.297	0.409	0.353	0.328	0.433	0.380
Woinadega	0.552	0.529	0.565	0.496	0.530	0.652	0.587	0.620	0.550	0.457	0.504	0.575	0.526	0.551
Kolla	0.059	0.060	0.108	0.081	0.095	0.040	0.064	0.052	0.123	0.136	0.130	0.097	0.041	0.069
Altitude	2210.510	2221.390	2125.410	2172.077	2148.744	2136.130	2160.490	2148.310	2157.363	2053.220	2105.292	2139.290	2261.220	2200.255
Inputs														
Labor_Hours per day	6.790	40.850	7.881	56.929	32.405	2.812	25.026	13.919	7.075	61.927	34.501	8.486	53.180	30.833
Amount of Manure and Compost per hectare	82.340	85.750	136.914	130.296	133.605	39.050	33.497	36.274	146.550	113.503	130.027	129.688	142.890	136.289

4.2 Food Security Status of the Households

Food Security status of the sampled households in the study area is identified using multidimensional food security index which is constructed using food security components/ dimensions: availability, accessibility, utilization and stability across time periods. The indicators used to proxy the four food security components are: for availability of food stock in the household: availability of food stock all the time for all members of the family, number of meals per day during good harvest and bad harvest times for their children and whole family respectively; for accessibility: affordability of prevailing food price; for utilization: access to pure drinking water, acquiring toilet facilities for the household; and for stability: whether household faced periodic shortfall of food items during the non-harvest periods.

The weights from the principal component analysis differ across four food security components since the influence of the various components is quite different in the study area. In order to estimate the multidimensional food security index for our analysis, we followed the approaches of Cavatassi *et al*. (2004) and pooled the data of the two rounds of the survey to get the principal components from the combined data.

The resulting weights from the combined data are then applied to the variable values of each rounds of the data using equation (1) in the methodology section above. In doing so, comparison among food security status of the households across time becomes possible as described in Cavatassi *et al*.(2004).

This is due to the fact that, since the variables used to construct the index and their respective weights of the food security components remained the same in the two rounds, we can use it to compare changes of food security status of the household over time.

Principal Component analysis results show that the first component explains 51.36 percent of the total variation in the data of food security indicators in the two rounds of the survey jointly. The second component explains 24.02 percent of the variations while the third and the fourth components explain 15.73 and 8.89 percent respectively.

Table 4.2.1 Summary statistics of food security indicators and component loadings

Indicator Variables	Mean	Standard Deviation	Component Loading*
Availability of food Stock	0.7134213	0.4522874	0.6105
Affordability of food price	0.7216722	0.448299	0.5212
Access to pure water and have toilet facility	0.7348735	0.441522	0.2056
Periodic shortage of food items	0.7431243	0.4370305	0.5598

Note: * Loadings corresponding to first component taken from factors pattern matrix

Source: Author's calculation from survey (2015 and 2016).

The value of the Kaiser-Meyer-Olkin (KMO) measure of sampling adequacy is 0.6521, which indicates relatively compact patterns of correlations (greater than 0.50) between the variables which proxy to explain food security status of the selected farm households. Hence, it is justifiable to use PCA to analyze the food security status of the selected households using the four food security components in our analysis (Kaiser 1974 and Dunteman1994).

To check the validity of the food security index in measuring food security status of selected farm households, correlation analysis is employed between the index and total household income, which include remittance. Total amount of household income is used in the correlation analysis to determine the appropriateness of our index because the household's capacity to fulfill their dietary need can be closely related to total household income including the remittance they got from family members, relatives and others. The results show that the index is significantly and positively correlated with total household income. Pearson correlation values of 0.30 and 0.26 for the years 2014/15 and 2015/16 ($P < 0.001$) indicate the validity of our index in measuring the relative food security status of farm households in the study area.

4.3 Empirical Results

4.3.1 Factors Explaining the Adoption of Climate Change Adaptation Practices

The results from the multinomial logit model are presented in Table 4.3.1.1. The base category is non-adoption ($I_0C_0F_0$), where different individual adaptation and combinations of adaptation results are compared. The results of our econometric analysis show that the model is fit enough for the data. The Wald test that all regression coefficients are jointly equal to zero is rejected (χ^2 (252) = 3146.04 ; p = 0.000). The results show that the estimated coefficients differ substantially across individual adaptation practices and combination of adaptation practices.

The adoption decision of farm household to apply packages of $I_1C_1F_0$ and $I_1C_1F_1$ adaptation strategies is positively correlated with getting climatic information from the agricultural extension service provider in their vicinity. This result is consistent with the result found by Di Falco *et al*.(2011a and 2011b) in Nile Basin of Ethiopia. The adoption of crop rotation to their farm plot is more likely influenced by the climatic information they got from their neighbors in the study area since they are positively correlated with each other. The probable reason for this is that neighbors can share and discuss about their life time experiences and the rationality behind choosing the right crop with certain climatic situation.

There is a strong correlation between the adoption of package $I_0C_1F_0$, $I_0C_1F_1$ and $I_1C_1F_1$ with the size of the family. This is perhaps because households with higher family size have more labor to contribute towards implementation of adaptation practices. Total annual income earned by a farm household is positively related to the adoption packages of $I_1C_1F_0$, $I_1C_0F_1$ and $I_1C_1F_1$. In other words, this suggests that households with higher income are more likely to adopt combinations of climate change adaptation strategies. The income they get from farming practice, non-farming activities and remittance from abroad/locally would help them to finance the costs of application of combined adaptation strategies.

Table 4.3.1.1

Parameter estimates of adoption of Climate Change Adaptation Packages: Multinomial Logit Selection Model

	Application of Inorganic Fertilizer ($I_0C_0F_1$)		Crop Rortation ($I_0C_1F_0$)		Improved Varaities ($I_1C_0F_0$)		Improved Varities and Crop Rotation ($I_1C_1F_0$)		Improved Varities and Fertilizer ($I_1C_0F_1$)		Crop Rotation and Fertilizer ($I_0C_1F_1$)		Improved Varities , Crop Rotation and Fertilizer ($I_1C_1F_1$)	
VARIABLES	**Coefficient**	**SE**	**Coefficient**	**SE**	**Coefficient**	**SE**	**Coefficient**	**SE**	**Coefficient**	**SE**	**Coefficient**	**SE**	**Coefficient**	**SE**
Household Characteristics														
HH_Head_Age	0.022	0.03	0.013	0.017	-0.003*	0.085	0.015	0.032	0.075	0.059	-0.01	0.019	-0.001***	0.018
HH_Head_Age_Square	0.0000	0.0000	0.0000	0.0000	0.0000	0.001	0.0000	0.0000	-0.001	0.001	0.0000	0.0000	0.0000	0.0000
Gender	0.087	0.235	0.109	0.129	-0.32	0.669	-0.537**	0.253	0.553	0.439	-0.024	0.144	0.085	0.135
Marital_Status	-0.103	0.191	0.02	0.104	0.363	0.549	0.403*	0.218	0.15	0.316	0.057	0.119	0.085	0.106
Literacy	0.063	0.116	0.246***	0.067	-0.175	0.33	0.165	0.126	-0.223	0.189	0.197***	0.075	-0.086	0.067
lHH_size	-0.213	0.174	0.372***	0.098	0.298	0.531	-0.081	0.192	0.043	0.299	0.203*	0.109	0.410***	0.102
Dependency_Ratio	0.133*	0.08	0.165***	0.044	0.362**	0.182	0.234***	0.08	-0.004	0.144	0.154***	0.05	0.021	0.048
lTotal_annua_income_earned	-0.012	0.013	0.0000	0.007	-0.019	0.037	0.071***	0.013	0.054***	0.02	-0.007	0.008	0.094***	0.007
Plot Characteristics														
Fertility_Index	0.32	0.226	-0.163	0.127	0.117	0.698	-0.620**	0.256	-0.106	0.382	-0.211	0.137	-0.450***	0.13
lAltitude	-1.611***	0.583	0.934***	0.26	-2.234	1.554	-0.995**	0.503	-1.713**	0.868	-2.719***	0.361	-1.263***	0.302
Slope_Index	0.009	0.254	-0.428***	0.144	-0.167	0.739	-0.13	0.287	-0.798*	0.438	-0.21	0.164	-0.291*	0.149
Shock_Index	3.278***	0.387	2.533***	0.237	0.597	1.341	2.298***	0.45	2.521***	0.683	3.001***	0.248	2.782***	0.241
Climatic Factors														
Mean_Temperature	2.878***	0.743	-1.553***	0.285	-2.142	1.74	-1.025*	0.545	-0.57	0.961	4.105***	0.436	0.493	0.33
SquaredMean_Temperature	-0.080***	0.02	0.040***	0.008	0.046	0.046	0.024	0.015	0.011	0.026	-0.108***	0.012	-0.013	0.009
Mean_Rainfall	0.086***	0.014	0.026***	0.007	0.014	0.065	0.090***	0.017	0.046*	0.026	0.099***	0.008	0.048***	0.007
SquaredMean_Rainfall	-0.000***	0.0000	-0.000***	0.0000	0.0000	0.0000	-0.001***	0.0000	0.0000	0.0000	-0.001***	0.0000	-0.000***	0.0000
CV_Temperature	24.396***	6.938	-19.961***	3.889	-16.23	29.702	-9.286	7.369	20.253*	12.256	36.771***	3.97	20.426***	3.639
CV_Rainfall	0.577	0.734	-2.772***	0.39	4.163*	2.438	-3.554***	0.75	-0.024	1.127	-2.878***	0.452	-5.276***	0.387
Climate_Information from any Source	0.396**	0.188	-0.239**	0.101	-0.451	0.522	-0.495**	0.201	-0.122	0.299	0.227**	0.113	-0.272**	0.107
Climatic_information_from_extension_off	-0.051	0.121	0.032	0.071	-0.111	0.409	0.325**	0.146	-0.116	0.205	-0.12	0.078	0.227***	0.073
Climatic_information_from_neighbor	0.109	0.11	0.114*	0.065	-0.583	0.366	0.041	0.127	-0.262	0.186	-0.069	0.068	-0.02	0.064
Climatic_information_from_media	-0.209*	0.11	-0.203***	0.065	-0.146	0.369	-0.045	0.13	0.21	0.195	-0.079	0.069	0.034	0.066

Table 4.3.1.1
(Continued)

	Application of Inorganic Fertilizer ($I_0C_0F_1$)		Crop Rortation ($I_0C_1F_0$)		Improved Varaities ($I_1C_0F_0$)		Improved Varities and Crop Rotation ($I_1C_1F_0$)		Improved Varities and Fertilizer ($I_1C_0F_1$)		Crop Rotation and Fertilizer ($I_0C_1F_1$)		Improved Varities , Crop Rotation and Fertilizer ($I_1C_1F_1$)	
VARIABLES	**Coefficient**	**SE**	**Coefficient**	**SE**	**Coefficient**	**SE**	**Coefficient**	**SE**	**Coefficient**	**SE**	**Coefficient**	**SE**	**Coefficient**	**SE**
Institutional Factors														
Land Certification	-0.488***	0.139	-0.127	0.082	-0.573	0.37	0.633***	0.142	-0.157	0.239	0.028	0.099	-0.074	0.085
Acess to Credit	0.072***	0.148	0.207***	0.076	0.033***	0.406	0.03***	0.162	0.194***	0.231	-0.108	0.086	0.063***	0.084
Access to Watershed Mang't Group	0.178*	0.102	0.238***	0.06	0.251	0.316	0.074	0.117	0.137	0.174	0.131**	0.064	0.246***	0.061
Meet Extension agent on Health and Sanitation	0.386*	0.216	0.078	0.099	2.052**	1.042	-0.125	0.185	-0.105	0.313	0.187	0.115	-0.131	0.105
Meet Extension agent on agriculture	0.091	0.117	-0.051	0.063	0.44	0.365	-0.018	0.124	0.389*	0.21	0.011	0.071	0.181***	0.067
Membership of agricultural cooperatives	0.06***	0.106	0.049	0.059	-0.104	0.308	-0.058	0.113	0.286	0.178	0.191***	0.065	0.111*	0.06
Mk't distance to Sell Outputs in minutes	0.002	0.001	0.0000	0.001	-0.002	0.005	-0.003*	0.002	0.0000	0.002	0.0000	0.001	-0.001	0.001
Mk't distance to get Inputs in minutes	0.002	0.002	0.001	0.001	0.005	0.005	0.001	0.002	0.003	0.003	0.003***	0.001	0.001	0.001
Assets														
Size of farm land	-0.060**	0.027	-0.092***	0.017	-0.039	0.072	-0.151***	0.041	-0.038	0.036	-0.052***	0.014	-0.078***	0.015
lTLU	0.187**	0.087	0.029	0.047	0.244	0.238	0.278***	0.093	0.197	0.142	0.296***	0.057	0.248***	0.05
lNumber of Beehive	0.002	0.071	0.055	0.04	-0.096	0.206	0.226***	0.069	-0.098	0.116	-0.056	0.05	0.048	0.04
Inputs														
Labor_Hours	0.014***	0.001	0.012***	0.001	0.015***	0.001	0.013***	0.001	0.014***	0.002	0.014***	0.001	0.013***	0.001
Amount of Manure and Compost	0.001***	0.0000	0.001***	0	0.002***	0	0.002***	0	0.002***	0	0.001***	0	0.001***	0.0000
Year_2016	-0.545***	0.137	-0.348***	0.078	-0.125	0.373	-0.670***	0.163	-0.096	0.216	-0.635***	0.082	-0.573***	0.078
Constant	-23.924***	5.703	11.008***	2.427	26.347**	12.997	17.801***	4.193	9.023	6.859	-21.059***	3.269	7.871***	2.444

Joint Level 0f Significance Wald $x^2(252) = 3146.04$; Prob. $> x^2 = 0.0000$; Psudo $R^2 = 0.0993$

Sample Size = 11,984

Note: *, ** and * indicates Statistical Significance at 10%, 5% and 1% respectively: SE is adjusted Standard errors**

Household head age is one of the determining factor of adopting improved varieties in isolation ($I_1C_0F_0$) or in combination with crop rotation and inorganic fertilizer ($I_1C_1F_1$). The results show that there is negative correlation between adopting improved varieties in isolation or as a package ($I_1C_1F_1$) with the age of the household head. This is perhaps because, as the household head gets older, they become risk averter and more reluctant to apply new technologies to their farm plot. This result is consistent with the findings of Fuglie (1999) for US, Kassie *et al*.(2012) for Tanzania and Teklewold *et al*.(2013) for Ethiopia.

The results of the multinomial regression model shows that those farm households who have a higher dependency ratio are more likely to adopt $I_0C_0F_1$, $I_0C_1F_0$, $I_1C_0F_0$, $I_1C_1F_0$ and $I_0C_1F_1$ than non-adopting any of them. This is perhaps because households with higher dependency ratio have less man power to undertake their agricultural practices and are forced to apply agricultural adaptation practices in order to boost or sustain their production in the ever changing environment.

The fertility of the plots which is proxied by the fertility index[11] of the soil is inversely correlated with the adoption decisions of $I_1C_1F_0$ and $I_1C_1F_1$ in households' farming plots. This suggests that the adoption of improved varieties, crop rotation and inorganic fertilizers more likely offset the infertility of the soil and would give them a better yield if they adopted them in their farm plots. The results also show that those farm households who have less fertile soil opted to use inorganic fertilizer to their farm which helps them to get better yield. This result is consistent with Kassie *et al*.(2012). In addition to usage of inorganic fertilizer application, they would rather apply it jointly with crop rotation and improved varieties to reap good harvest.

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[11] Fertility index results are interpreted as the index increases the fertility of the soil also increases

The slope of the plot, as proxied by the slope index[12], is positively correlated with the adoption decisions of $I_0C_1F_0$, $I_1C_0F_1$ and $I_1C_1F_1$. This is perhaps because as the slope index gets higher, the likely hood of adopting $I_0C_1F_0$, $I_1C_0F_1$ and $I_1C_1F_1$ increases to reduce the inconvenience/decline in the fertility of the pot due to erosion caused by higher slope. These adaptation practices would help the farmers to restrain the effect of slope on the production process by maintaining the level of production.

Different shocks that have happened to the farm plot are highly and positively correlated with the adoption decision of the farm household. This maybe because the effect of the shocks would probably minimize households' ability to get a better yield from their farm plots. The shocks are proxied by using shock index. The results of the regression show that the adoption of almost all adaptation strategies ($I_0C_0F_1$, $I_0C_1F_0$, $I_1C_1F_0$, $I_1C_0F_1$, $I_0C_1F_1$ and $I_1C_1F_1$) are highly correlated with shocks that happened to a given farm plot. These results are consistent with Teklewold *et al*.(2013) who find that whenever a given farm plot is affected by shocks they are more likely to apply adaptation strategies in isolation or in combination.

The effect of temperature on adoption of inorganic fertilizer as an adaptation measure to the changing climate is high and also positive until some level[13]but results vary by crop type and agro-ecology. Those farm household who adopt $I_0C_0F_1$ and $I_0C_1F_1$ are the one who benefit more from adoption of the packages when applied with increased temperature up to certain maximum level (3^{o}C) that the crops can afford to live with.

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[12] Slope Index results are interpreted as the index increases the slope of the soil also increases

[13] The rise in the temperature above 3^{o}C would affect agricultural activities negatively as described by Badolo KindaSomlanare *et al.* (2012), IPCC (2007)

The variation in temperature also has a significant positive impact on the adoption of $I_0C_0F_1$, $I_1C_0F_1$, $I_0C_1F_1$ and $I_1C_1F_1$. This suggests that application of the listed adaptation strategies given that the variation of the temperature coincides with the necessary timing that the crop needs and there is also enough water, the production results would be higher. That is if the crop would get a better temperature in the first growing periods/germination period given that having enough water supply the yield result becomes higher.

The rainfall of the study area is positively correlated with the adoption decisions of $I_0C_0F_1$, $I_0C_1F_0$, $I_1C_1F_0$, $I_1C_0F_1$, $I_0C_1F_1$ and $I_1C_1F_1$. Since the farming practice in the study area is governed by rainfall (rain fed agricultural practice), it is highly likely intertwined with the presence of enough rainfall. Contrary to the variation in temperature, the variation of rainfall pattern in the study area is negatively correlated with the adoption decisions of $I_0C_1F_0$, $I_1C_1F_0$, $I_0C_1F_1$ and $I_1C_1F_1$. These results can be explained by considering the results of application of improved varieties only. Application of improved varieties that are good enough to go with the environmental stress of the area, would result in increased outputs even though rainfall pattern somehow varies.

Land certification is negatively correlated with the adoption decision of inorganic fertilizer application. A possible reason for this relationship is farmers are more likely to use chemical fertilizer on rented-in plots than their own farm plots. This is because those farm household who rented-in the plots are highly focused on getting more from the land they rent from the owners than the long term use of the land itself. They over exploited the plot they rented-in by applying more and more inorganic fertilizer on it since the opportunity cost of land degradation doesn't concern them. These results are consistent with Allen and Lueck (1992), and Kassie and Holden (2007).

The adoption decisions of different adaptation strategies either individual adaptations ($I_0C_0F_1$, $I_1C_0F_0$, $I_0C_1F_0$) or combination of adaptations ($I_1C_1F_0$, $I_1C_0F_1$, $I_1C_1F_1$) have a positive correlation with the access to credit by farm households. A possible reason for this is when shortage of finance to cover costs of different adaptation strategies is an issue, they are more likely be able to fund the deficit by borrowing from the credit service providers in their proximity. This result is consistent with Deressa *et al*. (2012) and Di Falco *et al*.(2011a and 2011b). It is also to be noted that, access to watershed management group also positively determine the adoption decisions of $I_0C_0F_1$, $I_0C_1F_0$, $I_0C_1F_1$ and also $I_1C_1F_1$. A reason behind this could be, household members would have an opportunity of getting experiences from the members and also benefit from the preserved environment in their agricultural practices. Farm households also have the advantage of getting knew knowledge of doing their agricultural practice.

Interaction with agricultural extension agents about agricultural practices have a positive effect on the selection of the adoption decision to adopt $I_1C_0F_1$ and $I_1C_1F_1$ in their farm plot. Moreover, cooperative membership would also have a positive and significant impact in the adoption decision to select the application of $I_0C_0F_1$, $I_0C_1F_1$ and $I_1C_1F_1$. A likely reason for making the adoption decision in relation to being a cooperative membership is that if the farm household participates in the cooperative membership, it would help him/her to get new agricultural technologies and a better understanding of how to apply them on their farm plot. The result is consistent with Di Falco *et al*.(2011a) and Kassie *et al*.(2012).

Having a large farm size has a negative correlation in the adoption decisions of almost all ($I_0C_0F_1$, $I_0C_1F_0$, $I_1C_1F_0$, $I_0C_1F_1$ and $I_1C_1F_1$) adaptation practices under investigation. A possible reason for this is application of adaptations would increase cost of farm household as the size of the farm they hold increases.

The time needed to properly manage different climate change adaptation schemes would also increase as the size of the land holding increases. This result is consistent with Pender and Gebremedhin (2007), Deressa *et al*.(2012) and Kassie *et al*.(2012).

According to our multinomial logit model estimates, having large number of livestock have a positive and significant impact on the adoption decisions of $I_0C_0F_1$, $I_1C_1F_0$, $I_0C_1F_1$ and $I_1C_1F_1$. Those farm household who have large number of livestock have a better chance of adopting specified adaptation strategies because of having good amount of accumulated capital in the form of herds and outputs they got from their livestock as well which will help them to finance the adoption costs as compared to those who don't have any at all or with those who have a smaller number of livestock. In time of desperate needs, they can sell their livestock in order to get agricultural inputs which will make them confident to apply new agricultural technologies in their farm. This result is consistent with Deressa *et al*. (2012) and Kassie *et al.*(2012).

The average labor hours per day (both own and paid labor) farm households devoted to agricultural activities for the purpose of land preparation (plowing and planting), weeding, harvesting and threshing have a positive and significant impact on the selection decisions of all ($I_0C_0F_1$, $I_0C_1F_0$, $I_1C_0F_0$, $I_1C_1F_0$, $I_1C_0F_1$,$I_0C_1F_1$ and $I_1C_1F_1$) adaptation practices under investigation. As the number of hours the farm household working on his farm plot increases, the likelihood of understanding the changes that happened in the farm plot also increases. Moreover, this would give the farmer the chance to take a closer look at his farm which would benefit the farmer by giving him a clue about what is needed from him in the near future.

Therefore, one can easily see from the results and discussions above there are a number of factors which determine the adoption decision of farm household to select among different adaptation strategies whether they are applied in isolation or as packages. It is also to be noted that the sign and the level at which a given adoption determining factors affect adoption decisions is quite different within the adoption and also across packages of adaptations. Our result is also similar to Coretha and Edwin (2012) who found presence of differences among the determinants of adaptations in Tanzania.

4.3.2 Average Adoption Effects of Climate change Adaptations on Household Food Security Index

The results of the second stage estimates are done by using each adaptation practice under investigation individually and/or in combination as an independent variable to test the significance of variables in the food security index. The results of the estimates are presented in Table 4.3.2.1 below which shows the presence of significant variation among variables which affect the food security index of household's differently. The model estimates of all food security index are statistically significant, i.e., all results of the models, Prob. > F = 0.0000. Going through all the details become quite cumbersome and time taking since the very objective of this paper is to investigate the determinants of individual/combinations of adaptation practices, to check how a given adaptation practice affects the food security of farm households and lastly, to find-out about the relative effect of adoption on the adopters by using counterfactuals. To have some clue about the significance of different socio-economic, climatic and household characteristics on household food security index, we would go through a bird's eye view on some of the estimated results and their relative significance on household food security.

The age of household head positively and significantly affects the food security of the farm households who applied $I_0C_0F_1$ and $I_1C_1F_0$ as their adoption strategy. On the other hand, the age of the household head negatively and significantly affects the food security index of those households who applied $I_1C_0F_1$ and $I_1C_1F_1$ as their adoption strategy. The possible reason for the variation of the results which bases on the age of the household would be as the age of the household head increases the likelihood of adopting different combinations of adaptation will decline.

This is because those aged household heads would become more reluctant to take what they call "risk" of applying new technologies provided for them even though they know the benefits to some extent. Moreover, as the age of the head increases, they are highly likely governed by the traditional farming practices they adopted from their ancestors/parents than adopting new technologies like application of combined ($I_1C_1F_1$) adaptations.

As it is expected, the size of the households have a negative and significant effect on household food security index in almost all individual ($I_0C_0F_1$, $I_0C_1F_0$ and $I_1C_0F_0$) adoptions and/or combinations ($I_1C_1F_0$, $I_1C_0F_1$,$I_0C_1F_1$ and $I_1C_1F_1$) of adaptations. It also negatively affects those households who do not apply any of the adaptation practices ($I_0C_0F_0$) in their farm plot. This result is consistent with Abera *et al*.(2011) and Ginbo (2014).

Total annual income earned from farming practice, non-farming activities and remittance would help households to finance the costs of adaptation which consequently improve the food security of farm households. In all individual adaptations ($I_0C_0F_1$, $I_0C_1F_0$ and $I_1C_0F_0$) as well as packages of adaptations ($I_1C_1F_0$, $I_1C_0F_1$,$I_0C_1F_1$and $I_1C_1F_1$), food security of farm households would benefit more from the total annual income they earned during the study periods.

The total annual income earned will also have a positive and significant impact on those farm households who do not apply any of the specified adaptations at all. On the other hand, institutional factors such as access to credit, access to watershed management group and whether a farm household meet extension agents on health and sanitation also positively and significantly affect household food security with different sets of adaptation strategies.

Table 4.3.2.1

Food Security of farm household's with different Climate Change Adaptation Strategies

VARIABLES	FSI_NEW01		FSI_NEW02		FSI_NEW03		FSI_NEW05		FSI_NEW06		FSI_NEW07		FSI_NEW08	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Household Characteristics														
HH_Head_Age	-0.009	0.011	0.526***	0.088	-0.016	0.015	0.180*	0.096	-1.082***	0.1	-0.016	0.013	-0.054***	0.021
HH_Head_Age_Square	0.0000	0.0000	-0.002***	0.001	0.0000	0.0000	-0.001*	0.001	0.011***	0.001	0.0000	0.0000	0.000***	0.0000
Gender	0.037	0.085	-	-	0.258***	0.087	-0.393*	0.216	0.878***	0.099	0.493***	0.107	-1.037***	0.131
Marital_Status	0.092***	0.028	-0.523***	0.078	-0.121***	0.039	0.125	0.112	1.278***	0.074	0.105***	0.033	-0.144***	0.033
Literacy	-0.097	0.085	-	-	0.104	0.095	1.365***	0.28	-5.416***	0.49	-0.242*	0.124	0.048	0.107
lHH_size	-0.184***	0.04	-0.151	0.117	-0.044	0.055	-0.454***	0.097	-0.271	0.202	-0.181***	0.05	-0.242***	0.044
Dependency_Ratio	-0.009	0.016	0.039	0.031	0.02	0.019	-0.130***	0.042	0.599***	0.061	0.034	0.022	-0.097***	0.021
lTotal_annua_income_earned	0.102***	0.003	0.184***	0.009	0.078***	0.005	0.132***	0.01	0.106***	0.012	0.082***	0.005	0.085***	0.004
Plot Characteristics														
Fertility_Index	-0.090***	0.031	-0.078	0.058	0.036	0.042	-0.016	0.07	0.038	0.109	0.02	0.036	-0.048	0.037
lAltitude	20.608**	9.632	-	-	16.29	11.347	-3.702	11.521	-	-	2.959	5.026	7.454	5.005
Slope_Index	0.015	0.029	-0.042	0.072	0.143***	0.036	0.119*	0.069	-0.054	0.045	0.037	0.039	0.035	0.036
Shock_Index	0.098	0.062	0.403	0.34	-0.202	0.163	1.750***	0.32	3.946***	0.393	0.041	0.163	0.215	0.136
Climatic Factors														
Mean_Temperature	0.340**	0.163	1.197***	0.375	0.347*	0.196	0.909**	0.413	7.351***	0.516	0.111	0.183	-0.192	0.187
SquaredMean_Temperature	-0.010**	0.004	-0.033***	0.01	-0.010*	0.005	-0.026**	0.011	-0.213***	0.015	-0.003	0.005	0.005	0.005
Mean_Rainfall	0.045***	0.013	0.127*	0.069	-0.018	0.013	0.009	0.025	-0.434***	0.051	0.023	0.018	0.017	0.012
SquaredMean_Rainfall	-0.000***	0.0000	0.0000	0.0000	0.000**	0.0000	0.0000	0.0000	0.002***	0.0000	0.0000	0.0000	0.0000	0.0000
CV_Temperature	-7.660**	2.974	-28.173***	8.864	-9.917***	3.781	-22.035***	7.52	-31.007***	6.834	-7.827*	4.518	-2.397	3.438
CV_Rainfall	-1.172*	0.642	0.096	3.293	0.066	0.78	-2.388**	1.142	-5.248	3.232	-0.632	0.791	-0.982	0.987

Table 4.3.2.1

(Continued)

VARIABLES	FSI_NEW01		FSI_NEW02		FSI_NEW03		FSI_NEW05		FSI_NEW06		FSI_NEW07		FSI_NEW08	
	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE	Coefficient	SE
Institutional Factors														
Land Certification	-0.091***	0.025	-0.011	0.041	-0.085***	0.032	-0.051	0.054	-0.621***	0.11	-0.011	0.027	-0.072***	0.028
Acess to Credit	0.076***	0.018	0.031	0.038	0.076***	0.029	0.092**	0.039	0.607***	0.038	0.02	0.022	0.042**	0.021
Access to Watershed Mang't Group	0.024	0.016	0.284***	0.047	-0.001	0.022	0.051	0.043	0.119**	0.06	0.058**	0.023	0.023	0.02
Meet Extension agent on Health and Sanitation	0.265***	0.049	0.564***	0.103	0.110*	0.061	0.043	0.096	0.288**	0.143	-0.002	0.053	0.154***	0.054
Mk't distance to Sell Outputs in minutes	0.0000	0.0000	0.005***	0.001	0.0000	0.0000	0.007***	0.001	-0.007***	0.001	0.0000	0.0000	0.001**	0.0000
Mk't distance to get Inputs in minutes	0.001***	0.0000	-0.002***	0.001	0.0000	0.0000	-0.004***	0.001	-0.001	0.001	0.001***	0.0000	-0.001***	0.0000
Assets														
Size of farm land	-0.020***	0.004	-0.037**	0.018	-0.009	0.006	-0.070***	0.011	-0.080***	0.023	-0.020***	0.005	-0.023***	0.005
lTLU	-0.039**	0.019	-0.125**	0.051	-0.136***	0.025	0.018	0.05	0.441***	0.053	0.016	0.027	-0.100***	0.023
lNumber of Beehive	0.005	0.014	-0.04	0.028	0.008	0.018	0.052**	0.025	0.054	0.05	0.083***	0.017	0.036**	0.016
Inputs														
Labor_Hours	0.0000	0.0000	-0.002	0.001	0.0000	0.001	0.006***	0.001	0.016***	0.002	0.001	0.001	0.0000	0.0000
Amount of Manure and Compost	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.001***	0.0000	0.001***	0.0000	0.0000	0.0000	0.0000	0.0000
Year_2016	-0.093***	0.019	-	-	-0.085***	0.032	-0.201***	0.059	-0.474***	0.091	-0.117***	0.03	-0.093***	0.027
IMR1	-	-	0.143	0.096	0.024	0.046	-0.478***	0.09	-0.522***	0.073	-0.071	0.047	-0.047	0.037
IMR2	-0.012	0.032	-	-	0.068*	0.04	0.394***	0.063	0.970***	0.109	0.067**	0.033	0.086**	0.035
IMR3	-0.130***	0.04	-0.216**	0.109	-	-	0.087	0.079	-0.01	0.101	0.078	0.049	0.01	0.047
IMR4	-0.102***	0.018	-0.115***	0.034	0.012	0.023	-0.041	0.04	-0.069	0.055	0.0000	0.019	-0.066***	0.02
IMR5	0.262***	0.038	0.114	0.072	0.117***	0.042	-	-	0.158	0.183	0.115***	0.042	0.115***	0.034
IMR6	0.019	0.024	0.154***	0.054	-0.124***	0.03	-0.200***	0.054	-	-	-0.110***	0.027	-0.054**	0.026
IMR7	0.146***	0.039	0.259***	0.07	0.055	0.048	-0.335***	0.088	-0.166**	0.07	-	-	-0.081**	0.037
IMR8	-0.211***	0.039	-0.259***	0.096	-0.157***	0.054	0.421***	0.083	0.258**	0.101	-0.136***	0.044	-	-
Constant	25.721	82.762	-36.860***	8.01	43.887	109.596	425.656***	150.046	952.335***	183.139	211.718***	71.506	135.309**	66.625
*** p < 0.01, ** p < 0.05, * p < 0.1														
Observations		10,034		856		7,013		1,479		385		5,723		7,101
R-squared		0.336		0.812		0.282		0.467		0.975		0.331		0.300
Number of Households		715		52		505		99		25		394		489
	F(37, 9282) = 126.92 ; Prob. > F = 0.0000		F(33, 771) = 101.21 ; Prob. > F = 0.0000		F(37, 6471) = 68.69 ; Prob. > F = 0.0000		F(37, 1343) = 31.85 ; Prob. > F = 0.0000		F(36, 324) = 353.16; Prob. > F = 0.0000		F(37, 5292) = 70.91; Prob. > F = 0.0000		F(37, 6575) = 76.03; Prob. > F = 0.0000	

. testparam IMR2-IMR8	. testparam IMR1 IMR3-IMR8	. testparam IMR1 IMR2 IMR4-IMR8	. testparam IMR1-IMR4 IMR6-IMR8	. testparam IMR1-IMR5 IMR7-IMR8	. testparam IMR1-IMR6 IMR8	. testparam IMR1-IMR8
(1) IMR2 = 0 (5) IMR6 = 0	(1) IMR1 = 0 (5) IMR6 = 0	(1) IMR1 = 0 (5) IMR6 = 0	(1) IMR1 = 0 (5) IMR6 = 0	(1) IMR1 = 0 (5) IMR5 = 0	(1) IMR1 = 0 (5) IMR5 = 0	(1) IMR1 = 0 (5) IMR5 = 0
(2) IMR3 = 0 (6) IMR7 = 0	(2) IMR3 = 0 (6) IMR7 = 0	(2) IMR2 = 0 (6) IMR7 = 0	(2) IMR2 = 0 (6) IMR7 = 0	(2) IMR2 = 0 (6) IMR7 = 0	(2) IMR2 = 0 (6) IMR6 = 0	(2) IMR2 = 0 (6) IMR6 = 0
(3) IMR4 = 0 (7) IMR8 = 0	(3) IMR4 = 0 (7) IMR8 = 0	(3) IMR4 = 0 (7) IMR8 = 0	(3) IMR3 = 0 (7) IMR8 = 0	(3) IMR3 = 0 (7) IMR8 = 0	(3) IMR3 = 0 (7) IMR8 = 0	(3) IMR3 = 0 (7) IMR7 = 0
(4) IMR5 = 0	(4) IMR5 = 0	(4) IMR5 = 0	(4) IMR4 = 0	(4) IMR4 = 0	(4) IMR4 = 0	(4) IMR4 = 0
F(7, 9282) = 13.71 ; Prob. > F = 0.0000	F(7, 771) = 5.27 ; Prob. > F = 0.0000	F(7, 6471) = 8.30 ; Prob. > F = 0.0000	F(7, 1343) = 13.11 ; Prob. > F = 0.0000	F(7, 324) = 75.26 ; Prob. > F = 0.0000	F(7, 5292) = 11.03 ; Prob. > F = 0.0000	F(7, 6575) = 10.22 ; Prob. > F = 0.0000

Access to credit positively and significantly affects the food security of those farm household who adopt $I_0C_1F_0$, $I_1C_1F_0$, $I_1C_0F_1$, $I_0C_1F_1$and $I_1C_1F_1$. The non-adopters ($I_0C_0F_0$) are also significantly affected by having access to credit in their livelihood. Moreover, having access to watershed management group also positively and significantly affect household food security of those households who apply adaptation strategies of $I_0C_0F_1$, $I_1C_0F_1$ and $I_0C_1F_1$ in order to acquire food security.

Meeting government extension agents on health and sanitation positively and significantly affect the food security of those farm household's who adopt $I_0C_0F_1$, $I_0C_1F_0$, $I_1C_0F_1$ and $I_1C_1F_1$ as an adaptation strategy to the changing climate. On the other hand, those households who do not adopt any of the adaptation strategies at all are also significantly and positively impacted their food security by having meet with government extension agents on health and sanitation. The possible reason of meeting government extension agents on health and sanitation resulted in helping being food secure given that different combinations of adaptation strategy applications is that those households who have access to improve their health and sanitation status would result in providing efficient labor to be utilized in their farming practices. It also helps farmers to have a productive and efficient man power in their farming; it will also help household members properly utilize the food they eat to make them productive and resistant to disease prevalence.

The other important institutional factor which affects household members to be food secure is access to watershed management group. Having access to watershed management group positively and significantly affects the food security of those farm households who adopt $I_0C_0F_1$, $I_1C_0F_1$ and $I_0C_1F_1$ .A possible reason for this is that membership of farm households in such groups would give them a chance to learn from the others to answer the questions of (how to, when and how much) to apply a given adaptation strategy in their farm plot.

Moreover, membership in watershed management groups can help improve environmental situations in their surroundings which ultimately results in again from agricultural practices. The details of the results of different characteristics and adaptation strategies are presented in Table 4.3.2.1 above.

Once again, we can see from the results and discussions above there are a number of factors which determine the food security of farm household linked with different adaptation strategies applied in isolation as well as in combinations. It is also to be noted that the sign and the level at which factors affect food security of farm household is quite different within and/or among adaptations.

Moreover, many of the selection correction terms are statistically significant at the 5% level, suggesting that individual adaptations as well as packages of adaptation practices will not have the same effects on non-adopters should they choose to adopt, as it will on adopters. This is an evidence of self-selection in the adoption of individual adaptations and/or packages of adaptation practices. It can easily be seen from the estimated results that a number of variables in the fixed effect model have shown significant correlation with the outcome variable (the food security index of farm households) and there are differences between the outcome equations coefficients among the different individual or package adopter groups. This illustrates the heterogeneity in the sample with respect to the food security index of the farm households'.

From the fixed effects regression estimates, we derive the unconditional and conditional average effect of adoption of various combination of improved varieties, application of inorganic fertilizer and crop rotation. The unconditional average effect is presented in Table 4.3.2.2 below.

Table 4.3.2.2 The unconditional average effect of adoption of Improved variety (I), Crop Rotation (C) and application of Inorganic Fertilizer (F) in the Nile Basin of Ethiopia (Results from fixed effect estimation)

Climate Change Adaptation Strategy Packages	Food Security Index	Adoption Effect
$I_0C_0F_0$	-0.0112195 (0.0387679)	-
$I_0C_0F_1$	0.4434202 (0.0333205)	0.4546397 (0.0511195)**
$I_0C_1F_0$	0.34085 (0.0295238)	0.3520695 (0.2487299)**
$I_1C_0F_0$	0.5749828 (0.0148676)	0.5862023 (0.341521)**
$I_1C_1F_0$	0.6784818 (0.106443)	0.6897013 (0.4402026)**
$I_1C_0F_1$	1.471199 (0.510622)	1.482419 (0.0641116)**
$I_0C_1F_1$	1.5097825 (0.4763815)	1.521002 (0.7392896)**
$I_1C_1F_1$	1.7472674 (0.3134623)	1.7584869 (0.7410388)**

Note: figures in parenthesis are standard errors; *, ** and *** indicate statistical significance level at 10%, 5% and 1% respectively.

The unconditional average effects indicate that adopters of any of the climate change adaptation practices in isolation or in combinations on average improve food security index of the household who applied in their farm plot than the non-adopters. This naive comparison would lead to misleading conclusion because the approach doesn’t consider the possibility that the difference in the outcome variables may be caused by observable and unobservable characteristics.

On the other hand, to avoid this blurred visualization of the adoption effect and present the true average adoption effect of the adopters, we applied a counterfactual analysis. In doing so, we get the following results from our analysis. The results of our analysis using the counterfactual groups to our model presents the true average adoption effects of different adoptions (applied in isolation or as a package) on household food security index. Table 4.3.2.3 presents the detailed results of adoption using counterfactuals conditions.

In the upper panel of this table, the outcome variable(food security index of the household) of farm households who adopted individual adaptations and/or packages of adaptation are compared with the outcome variable if the farm households had not adopted. This is done by applying the counterfactuals in to our model using equation (10). We also present the average treatment effects for the untreated in lower panel of this table where the outcome variable of farm households who don't adopt the individual adaptation or packages of adaptation are compared with their outcome variable (food security index) if the farm households had adopted by using equation (11). In order to determine the average adoption effects, we compare the first column (I) and column (II) of Table 4.3.2.3. The last column (III) of Table 4.3.2.3 presents the impacts of adoption of individual and/or combinations of climate change adaptation practices on household food security index computed as the difference between the above twocolumns[14].

Results show that the adoption of either any of climate change adaptation practice in isolation or in combination provides higher food security index compared with non-adoption except for crop rotation application in isolation.

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[14] Detailed results can be found in the APPENDICES.

Table 4.3.2.3 Average expected Food Security Index with adoption of climate change adaptation strategies effect (Results from fixed effect estimation)

	Sample Outcome	Adoption Status		
		Adoption (j = 2,…8) I	Non-Adoption (j = 1) II	Adoption Effect III
Adopters	$E\ (Q_j \| I = 2)$	0.3799797 (0.1641243)	-0.033277 (0.126604)	0.4132567 (0.2072809)**
	$E\ (Q_j \| I = 3)$	-0.0000676 (0.0848627)	0.494094 (0.1109444)	-0.4941655 (0.1396794)**
	$E\ (Q_j \| I = 4)$	-0.2427311 (0.1634428)	-0.972503 (0.7470673)	0.729772 (0.7647373)**
	$E\ (Q_j \| I = 5)$	0.4124637 (0.0621611)	-0.7528728 (0.2821521)	1.165336 (0.2889183)**
	$E\ (Q_j \| I = 6)$	-0.0339706 (0.3632613)	-1.3882525 (0.3075984)	1.3542819 (0.3759995)**
	$E\ (Q_j \| I = 7)$	1.513746 (0.3017520)	-0.0238346 (0.0117784)	1.5375806 (0.8613117)**
	$E\ (Q_j \| I = 8)$	1.4218108 (0.3285337)	-0.3342186 (0.1808759)	1.7560276 (0.4857618)**
Non-Adopters	$E\ (Q_j \| I = 1)$	-0.5083604 (0.0561839)	-0.547223 (0.06427417)	0.0388626 (0.1853441)**
	$E\ (Q_j \| I = 1)$	-0.6719412 (0.0485427)	-0.547223 (0.06427417)	-0.1247182 (0.0805195)**
	$E\ (Q_j \| I = 1)$	-0.0664909 (0.0230345)	-0.547223 (0.06427417)	0.4807321 (0.0682465)**
	$E\ (Q_j \| I = 1)$	0.3417828 (0.01809)	-0.547223 (0.06427417)	0.8890058 (0.0667401)**
	$E\ (Q_j \| I = 1)$	0.6858194 (0.0830451)	-0.547223 (0.06427417)	1.233042 (0.1049928)**
	$E\ (Q_j \| I = 1)$	0.7806654 (0.0108668)	-0.547223 (0.06427417)	1.327884 (0.4651543)**
	$E\ (Q_j \| I = 1)$	0.8979905 (0.0223463)	-0.547223 (0.06427417)	1.4452135 (0.5680173)**

Note: ‘j’ represents package of Climate Change adaptations; figures in parenthesis are standard errors; *, ** and *** indicate statistical significance at 10%, 5% and 1% level

Crop rotation application as an adaptation strategy is expected to have a positive and significant effect on production and also on food security of households; for instance, the benefits of crop rotation include helping farmers to control pests and weeds, improving soil structure, preventing soil erosion, and nitrogen fixation. Possible gains from rotation can become real if and only if crops are properly rotated.

Whenever crop rotation is applied in isolation or in combination with other adaptation practices, it requires a proper planning with regards to crop choice which has to respond to a number of conditions (soil type, climatic conditions and the overall agro-ecology) and also the upcoming product market and labor supply needs to be taken into considerations.

Thus, planning failure would penalize the farmers when they choose among alternative crop rotations. If the farm households rotate crops wrongly, it would create an imbalance in the soil nutrient content and also sometimes resulted in creating pathogens which affect the outcome negatively. According to Rosenzweig and Binswanger (1993) and Badolo, KindaSomlanare (2012), climate change can force the decisions made by farmers about what crops to grow. This shifting planting decision of crops which is done as a result of climate change can alter micronutrient availability for households' consumption. This situation could hinder households from becoming food secure even though they applied crop rotation in their farm plot. These are possible reasons for a negative (-0.4941655)effect on the food security index from adoption of crop rotation in isolation ($I_0C_1F_0$).

In all counterfactual cases, farm households who actually adopted would have had less food security index if they did not adopt (see column II of Table 4.3.2.3 of adopters row). Importantly, it is interesting to note that irrespective of the type of practices, as the number of practices in the combination increases, the food security index of the farm household also increases as well. The largest food security index exhibited (1.7590276) is obtained from adoption of improved varieties jointly with application of inorganic fertilizer and crop rotation ($I_1C_1F_1$).

Adoption of improved varieties in isolation($I_1C_0F_0$) provide households the highest food security index (0.729772) than adoption of other adaptation practices in isolation. Adoption of improved varieties in combination with application of inorganic fertilizer ($I_1C_0F_1$) also provide households with the highest food security index (1.5375806) compared with the food security index obtained from a combination of any two practices under investigation. Similar trend is also observed for the average treatment effects of the untreated. For the counterfactual condition of adoption by farm households that did not actually adopt, these households would have increased food security index if they did adopt (see column I of Table 4.3.2.3, non-adopters row). Importantly, again, the food security index increases as the number of practices included in combination increases. Adoption of improved varieties in isolation($I_1C_0F_0$)or in combination with application of inorganic fertilizer ($I_1C_0F_1$) has a positive impact on the improvement of household food security index compared with adoption of any other single practice or any other two practices. The highest food security index exhibited (1.4452135) is achieved from adopting a combination of three practices: improved varieties, application of inorganic fertilizer and crop rotation ($I_1C_1F_1$) for the counterfactuals.

The result from adopting crop rotation in isolation ($I_0C_1F_0$) for the counterfactual groups is similar to the adopter with negative outcome, i.e. food security index of -0.1247182. When we look at the results of the food security index of the adopters and their counterfactuals, we can see that there is a slight decline in food security index of the counterfactuals. A possible reason for the relatively good stand for non-adopters can be attributed to advantage of having fertile soil and less prevalence to shocks as compared to the adopter farm households plot. This result is also supported by the descriptive analysis in this study.

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Adoption of different climate change adaptation strategies and analyzing the effects of adoption have received considerable attention. With the exceptions of Teklewold *et al*. (2013) for Ethiopia and Kassie *et al*.(2012) for Tanzania, most of previous research reviewed here focuses on adaptation practices in isolation. Hence, they resulted in having less information about the possible effects of individual and/or combinations of adaptations at a time.

Teklewold *et al*. (2013) and Kassie *et al*. (2012) applied a simultaneous adoption of multiple and interdependent adaptation strategies and analyzed their possible impacts on outcome variables in detail. The purposes of this thesis are: to improve understanding of farmers' adoption selection decisions of individual and combinations of climate change adaptation strategies, to understand the effects of adopting individual and/or packages of adaptations on food security index of the farm household and to assess the possible difference in food security index between adopters of individual adaptation strategies, adopters of combinations of adaptation strategies and non-adopters. The analysis is done for farm households using plot-level panel data collected in 2014/15 and 2015/16 in the Nile Basin of Ethiopia. We used a multinomial endogenous switching regression methodology, where selectivity is modeled as a multinomial logit and fixed effects model in the second stage including the self-selection bias correction terms.

The multinomial logit selection model results show that the likelihood of adoption of individual and/or packages of adaptation strategies is influenced by household-characteristics, plot-characteristics, climatic and institutional factors as well as household asset ownership.

More specifically, the variables that are important in determining the decision to adopt individual and combinations of adaptation strategies and are grouped under household-characteristics include: family size, literacy of household head, dependency ratio and total annual income earned by the household. Variables at the plot level include: fertility of the soil, different kinds of shocks to the plot and the landscape of the plot which is related to the slope of the plot. Climatic-factors include: temperature and rainfall levels, coefficient of variation of temperature and rainfall, access to climatic information from any source (including neighbors and from extension agents).

Institutional factors include: land certification, access to credit, having access to watershed management group and agricultural cooperatives, meeting extension agents on health and sanitation and on agricultural practices, market distance to get inputs and to sell outputs. Variables related to asset holdings include: the size of the farm the household owned, number of livestock (in TLU) owned by household, labor hour spent in agricultural practice and the number of beehives owned by the household. We have to keep in mind that, the sign and size of the effects of these variables differs.

Therefore, farm households that are highly likely to apply individual and/or combinations of adaptation strategies in their farm plots in the Nile basin of Ethiopia are those: who have large family size, have more livestock and beehives, spend extended labor hours for farming practice, have higher total annual income, have certified plots which are relatively less frequently hit by shocks with flat slope and fertile soil, who got reliable climatic information from neighbors as well as from agricultural extension agents, have access to credit and are a member of agricultural cooperatives, got sufficient amount of rainfall and temperature for their agriculture.

With regard to the effects of adoption of improved varieties, inorganic fertilizer and crop rotation, the following conclusions can be derived. First, adoption of improved varieties with or without the application of inorganic fertilizer increases household food security index, i.e., it reduces the likelihood of food insecurity in the farm household who adopt improved varieties with or without the application of inorganic fertilizer. The highest food security index was achieved when farmers adopt improved varieties, inorganic fertilizer and crop rotation jointly rather than in isolation.

On the other hand, application of crop rotation in isolation as an adaptation strategy resulted in negative household food security index in the study area. The result is similar for the counterfactuals but the degree/level of food insecurity is lower for the counterfactuals than to that of the adopter households. These differences are attributed to the enhanced plot characteristics owned by non-adopter farm households, i.e. non-adopter farm households' plots are characterized by relatively fertile, flat slope and also have lower shock index than adopters' plot.

The possible reason for having unintended/unwanted results from application of crop rotation as an adaptive measure could be due to inappropriate crop rotation done by the farmers and also inappropriate rotation planning implementations. Proper crop rotation requires: proper planning with regards to crop choice which has to respond to soil type, climatic conditions and agro-ecology and also making analysis of their future product market and labor supply needs to be considered. On the contrary, crop rotation experience of Ethiopian farmers is highly governed by local knowledge without enough support by modern technologies aggravated by information asymmetry about climatic conditions which is highly likely to result in negative outcomes from crop rotation in the study area.

Moreover, Rosenzweig and Binswanger (1993) and Badolo, KindaSomlanare (2012) find that climate change can force the decisions made by farmers about what crops to grow. This shifting planting decision of crops which is done as a result of climate change can alter micronutrient availability for household consumption.

In analyzing the food security status of households, those farmers who applied different adaptation strategies other than crop rotation in isolation exhibited higher food security index than non-adopter farm households. These results explain the benefits of combined (package) applications of adaptation strategies to attain household food security. The results also show that application of all the three adaptation strategies under investigation: improved varieties, crop rotation and inorganic fertilizer would improve household food security status in the Nile Basin of Ethiopia.

5.2. Recommendations

The findings of this study are particularly important to design policies for effective promotion of individual as well as combinations (packages) of climate change adaptation in order to enhance households' food security in the Nile basin of Ethiopia. Individual and/or combinations of adaptations have to be encouraged through their positive impacts on food security status of farm households who adopt. Hence, this study draws the following policy implications to help households improve their food security status:

- Providing farmers with timely and reliable climatic information is an important factor that can help households adapt to climatic change in their agricultural practices. Thus, government and stakeholders should engage intensively on timely provision of climatic information/forecasts, and provision of assistance and trainings about how to deal with the changing environment.
- Having access to credit would help farm households in order to get different agricultural inputs at the time of shortfall. Moreover, it will help them to offset credit constraint that households face especially at the beginning of farming. This is because the beginning periods of agriculture are known to be highly correlated with larger expenses in relation to input requirements. Therefore, credit facilitation in their vicinity would help farmers to finance climate change adaptations such as improved varieties and inorganic fertilizer which resulted in helping them to be food secure. It is also to be noted that membership of agricultural cooperatives and access to watershed management groups have a significant positive impact on households’ food security status. Hence, strengthening the cooperatives and creating a competitive environment among different groups would result in a better food security of farm households in the study area.

- Provision of intense extension service on household health and sanitation would result in proper utilization of the food they eat and minimize prevalence of climate change driven diseases, such as malaria and cholera. This would help farm households to be more efficient and effective in their agriculture since they do have healthy and efficient labor to be supplied which ultimately helps them to be food secure.
- Filling the knowledge gap about how crops are rotated, i.e. helping farm households how to properly plan crop rotation and harmonize their local knowledge with modern and efficient application of crop rotation practice would result in gain from crop rotation. These include acquiring a well-organized and structured crop rotation plan with precise forecasting future price and the labor demand as well. Fulfilling those stated situations above leads farm households to benefit more (increased food security) from adoption of crop rotation in isolation or using packages than the current adoption gain. Moreover, government and other stakeholders should focus their research more on producing climate resilient varieties which have all the necessary micronutrients needed to lead an active daily life.
- Strengthening ties between community members to share experience about best performing farm households or the so called "role model farm households" in fulfilling households' food security requirements and their adaptive capacity to the changing environment by giving them recognition in order to initiate and to be followed. Moreover, government and other stakeholders should provide climate change adaptation packages to households with affordable and reasonable prices in their vicinity to enhance household food security.
- Even though our results show that adoption of individual and/or packages of adaptation practices improve food security when households adopt them than when not adopting them, there are still a section of farm households who do not benefit yet from adoption to become food secure. Therefore, there is a lot to be done in explaining and disseminating information about the benefits of adoption of individual or packages of adaptation practices to improve the food security of farm households in the study area.

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APPENDICES

A1: PRINCIPAL COMPONENT ANALYSIS OF HOUSEHOLD MULTIDIMENSIONAL FOOD SECURITY INDICATORS

```
Principal components/correlation                  Number of obs    =      1818
                                                  Number of comp.  =         4
                                                  Trace            =         4
    Rotation: (unrotated = principal)             Rho              =    1.0000

    ──────────────────────────────────────────────────────────────────────────
       Component │   Eigenvalue   Difference         Proportion   Cumulative
    ─────────────┼────────────────────────────────────────────────────────────
           Comp1 │      2.05436      1.09358             0.5136       0.5136
           Comp2 │      .960779      .331414             0.2402       0.7538
           Comp3 │      .629365      .273869             0.1573       0.9111
           Comp4 │      .355496            .             0.0889       1.0000
    ──────────────────────────────────────────────────────────────────────────

Principal components (eigenvectors)

    ────────────────────────────────────────────────────────────────────
        Variable │    Comp1     Comp2     Comp3     Comp4 │ Unexplained
    ─────────────┼────────────────────────────────────────┼─────────────
    availability │   0.6105   -0.0850   -0.1584   -0.7713 │           0
    accessibil~y │   0.5212   -0.0448    0.8147    0.2501 │           0
     utilization │   0.2056    0.9703   -0.1018    0.0768 │           0
       stability │   0.5598   -0.2220   -0.5484    0.5802 │           0
    ────────────────────────────────────────────────────────────────────
```

Source: Analysis based on survey data of 2014/15 and 2015/16 using STATA Software

A2: KAISER-MEYER-OLKIN MEASURE OF SAMPLING ADEQUACY OF HOUSEHOLD MULTIDIMENSIONAL FOOD SECURITY INDICATORS

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. estat kmo, novar

Kaiser-Meyer-Olkin measure of sampling adequacy (overall) =  0.6521
```

Source: Analysis based on survey data of 2014/15 and 2015/16 using STATA Software

A3: SUMMARY STATISTICS OF HOUSEHOLD MULTIDIMENSIONAL FOOD SECURITY INDICATORS

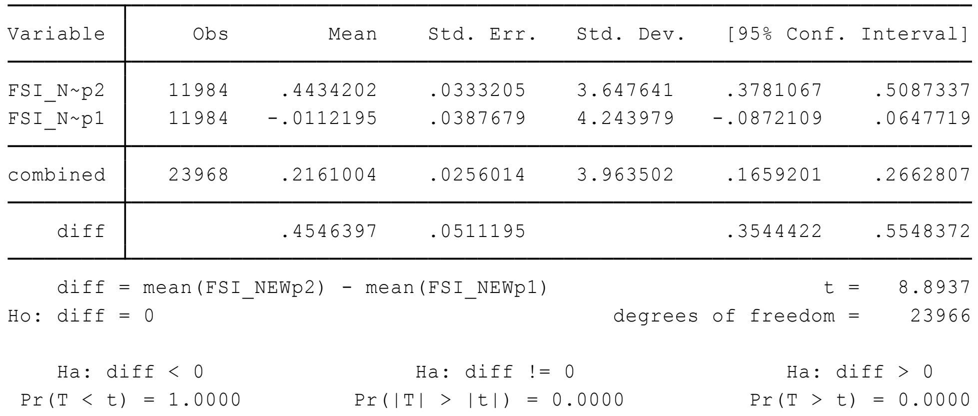
Year_2015	Variable	Observation	Mean	Std.Dev.	Min	Max
	Availability	909	0.7183718	0.4500406	0	1
	Accessibility	909	0.7293729	0.4445283	0	1
	Utilization	909	0.753554	0.4311659	0	1
	Stability	909	0.7271727	0.445658	0	1
Year_2016						
	Availability	909	0.7084708	0.4547168	0	1
	Accessibility	909	0.7139714	0.4521517	0	1
	Utilization	909	0.7161716	0.4511028	0	1
	Stability	909	0.7590759	0.4278798	0	1
Summary						
	Availability	1818	0.7134213	0.4522874	0	1
	Accessibility	1818	0.7216722	0.448299	0	1
	Utilization	1818	0.7348735	0.441522	0	1
	Stability	1818	0.7431243	0.4370305	0	1

Source: Analysis based on survey data of 2014/15 and 2015/16 using STATA Software

A4 :UNCONDITIONAL FOOD SECURITY INDEX OF HOUSEHOLDS

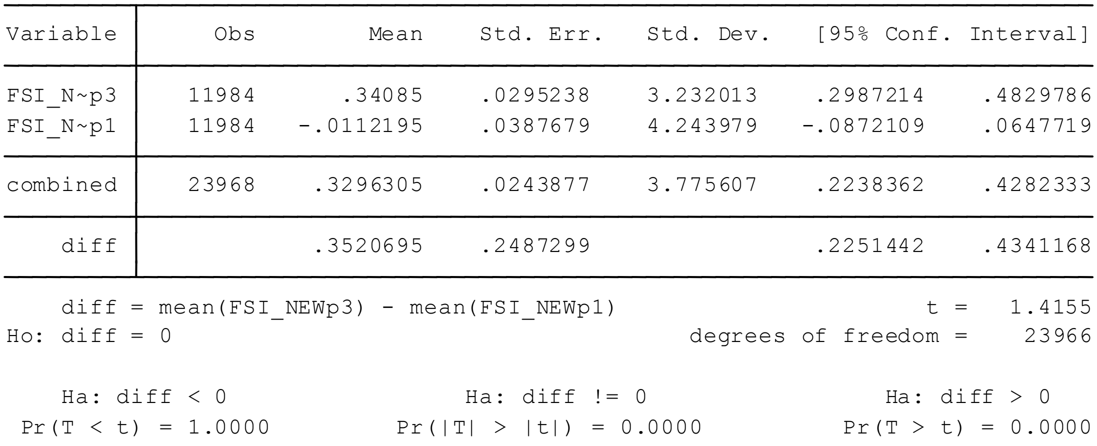
Variable	Observation	Mean	Std.Dev.	Min	Max
FSI_NEWp1	11984	-0.0112195	4.243979	-20.02839	6.676896
FSI_NEWp2	11984	0.44324202	3.647641	-11.38337	11.41811
FSI_NEWp3	11984	0.34085	3.232013	-16.00592	5.109186
FSI_NEWp4	11984	0.5749828	1.627583	-7.73657	27.57127
FSI_NEWp5	11984	0.6784818	1.165246	-3.163256	4.811394
FSI_NEWp6	11984	1.471199	5.589854	-15.59853	27.03554
FSI_NEWp7	11984	1.5097825	0.6985919	-3.496762	1.915364
FSI_NEWp8	11984	1.7472674	1.473735	-7.095191	3.637465

A5 :COMPARISON OF UNCONDITIONAL FOOD SECURITY INDEX OF HOUSEHOLDS



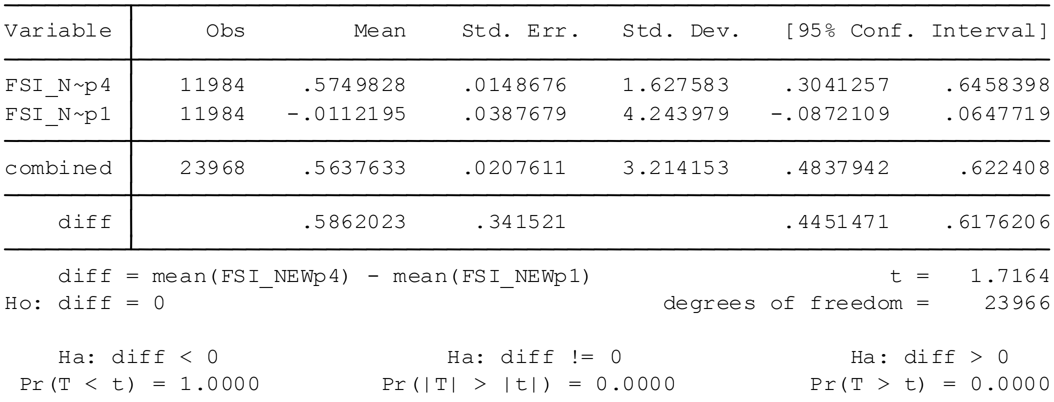
```
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_N~p2 |   11984    .4434202    .0333205    3.647641    .3781067    .5087337
FSI_N~p1 |   11984   -.0112195    .0387679    4.243979   -.0872109    .0647719
---------+--------------------------------------------------------------------
combined |   23968    .2161004    .0256014    3.963502    .1659201    .2662807
---------+--------------------------------------------------------------------
    diff |            .4546397    .0511195                .3544422    .5548372
------------------------------------------------------------------------------
    diff = mean(FSI_NEWp2) - mean(FSI_NEWp1)                      t =   8.8937
Ho: diff = 0                                     degrees of freedom =    23966

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```



```
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_N~p3 |   11984      .34085    .0295238    3.232013    .2987214    .4829786
FSI_N~p1 |   11984   -.0112195    .0387679    4.243979   -.0872109    .0647719
---------+--------------------------------------------------------------------
combined |   23968    .3296305    .0243877    3.775607    .2238362    .4282333
---------+--------------------------------------------------------------------
    diff |            .3520695    .2487299                .2251442    .4341168
------------------------------------------------------------------------------
    diff = mean(FSI_NEWp3) - mean(FSI_NEWp1)                      t =   1.4155
Ho: diff = 0                                     degrees of freedom =    23966

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```



```
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_N~p4 |   11984    .5749828    .0148676    1.627583    .3041257    .6458398
FSI_N~p1 |   11984   -.0112195    .0387679    4.243979   -.0872109    .0647719
---------+--------------------------------------------------------------------
combined |   23968    .5637633    .0207611    3.214153    .4837942     .622408
---------+--------------------------------------------------------------------
    diff |            .5862023     .341521                .4451471    .6176206
------------------------------------------------------------------------------
    diff = mean(FSI_NEWp4) - mean(FSI_NEWp1)                      t =   1.7164
Ho: diff = 0                                     degrees of freedom =    23966

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

```
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_N~p5 |   11984    .6784818    .0106443    1.165246    .5576173    .7993464
FSI_N~p1 |   11984   -.0112195    .0387679    4.243979   -.0872109    .0647719
---------+--------------------------------------------------------------------
combined |   23968    .6672623    .0201102    3.113386    .5442139    .7230485
---------+--------------------------------------------------------------------
    diff |            .6897013    .4402026                .5109016     .768501
------------------------------------------------------------------------------
    diff = mean(FSI_NEWp5) - mean(FSI_NEWp1)                      t =   1.5668
Ho: diff = 0                                     degrees of freedom =    23966

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

```
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_N~p6 |   11984    1.471199    .0510622    5.589854    1.371109    1.571289
FSI_N~p1 |   11984   -.0112195    .0387679    4.243979   -.0872109    .0647719
---------+--------------------------------------------------------------------
combined |   23968    .7299898    .0324107    5.017699    .6664628    .7935169
---------+--------------------------------------------------------------------
    diff |            1.482419    .0641116                1.356756    1.608081
------------------------------------------------------------------------------
    diff = mean(FSI_NEWp6) - mean(FSI_NEWp1)                      t =  23.1225
Ho: diff = 0                                     degrees of freedom =    23966

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

```
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_N~p7 |   11984   1.5097825    .4763815    .6985919   1.0222913   1.6027262
FSI_N~p1 |   11984   -.0112195    .0387679    4.243979   -.0872109    .0647719
---------+--------------------------------------------------------------------
combined |   23968    1.566782    .0196444    3.041268   -.0490053    .0280033
---------+--------------------------------------------------------------------
    diff |            1.521002    .7392896               1.3755732   1.6784471
------------------------------------------------------------------------------
    diff = mean(FSI_NEWp7) - mean(FSI_NEWp1)                      t =   2.0574
Ho: diff = 0                                     degrees of freedom =    23966

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

```
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_N~p8 |   11984   1.7472674    .3134623    1.473735   1.6808791   1.8336556
FSI_N~p1 |   11984   -.0112195    .0387679    4.243979   -.0872109    .0647719
---------+--------------------------------------------------------------------
combined |   23968   1.7360479    .0205311    3.178544   1.5577817   1.8382662
---------+--------------------------------------------------------------------
    diff |           1.7584869    .7410388               1.6380482   1.8989255
------------------------------------------------------------------------------
    diff = mean(FSI_NEWp8) - mean(FSI_NEWp1)                      t =   2.3730
Ho: diff = 0                                     degrees of freedom =    23966

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

A6: COMPARISON OF CONDITIONAL FOOD SECURITY INDEX: EXPECTED ADOPTION EFFECT FOR THE TREATED (ADOPTER)

```
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_~022 |     501    .3799797    .1641243    3.673599    .0575214     .702438
FSI_~012 |     501    -.033277     .126604    2.833781   -.2820184    .2154644
---------+--------------------------------------------------------------------
combined |    1002    .1733513    .1037943    3.285546   -.0303281    .3770308
---------+--------------------------------------------------------------------
    diff |            .4132567    .2072809                .0065013    .8200121
------------------------------------------------------------------------------
    diff = mean(FSI_NEW022) - mean(FSI_NEW012)                    t =   1.9937
Ho: diff = 0                                     degrees of freedom =     1000

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.9768         Pr(|T| > |t|) = 0.0465          Pr(T > t) = 0.0232
```

```
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_~033 |    2301   -.0000676    .0848627    4.070755   -.1664829    .1663478
FSI_~013 |    2301     .494098    .1109444    5.321865    .2765364    .7116596
---------+--------------------------------------------------------------------
combined |    4602    .2470152    .0699271    4.743715    .1099246    .3841058
---------+--------------------------------------------------------------------
    diff |           -.4941655    .1396794               -.7680042   -.2203269
------------------------------------------------------------------------------
    diff = mean(FSI_NEW033) - mean(FSI_NEW013)                    t =  -3.5379
Ho: diff = 0                                     degrees of freedom =     4600

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0002         Pr(|T| > |t|) = 0.0004          Pr(T > t) = 0.9998
```

```
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_~044 |      54   -.2427311    .1634428    1.201055   -.5705559    .0850938
FSI_~014 |      54    -.972503    .7470673    5.489801   -4.470931   -1.474076
---------+--------------------------------------------------------------------
combined |     108    -.607617    .4028024    4.186045    -.406126   -.8091084
---------+--------------------------------------------------------------------
    diff |             .729772    .4327373                -.213606    1.245938
------------------------------------------------------------------------------
    diff = mean(FSI_NEW044) - mean(FSI_NEW014)                    t =   1.6864
Ho: diff = 0                                     degrees of freedom =      106

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.9997         Pr(|T| > |t|) = 0.0005          Pr(T > t) = 0.0003
```

```
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_~055 |     411    .4124637    .0621611    1.260201    .2902693     .534658
FSI_~015 |     411   -.7528728    .2821521    5.720107   -1.307518   -.1982275
---------+--------------------------------------------------------------------
combined |     822   -.1702045    .1457963    4.180058   -.4563819    .1159728
---------+--------------------------------------------------------------------
    diff |            1.165336    .2889183                .5982298    1.732443
------------------------------------------------------------------------------
    diff = mean(FSI_NEW055) - mean(FSI_NEW015)                    t =   4.0334
Ho: diff = 0                                     degrees of freedom =      820

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0001          Pr(T > t) = 0.0000
```

```
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_~066 |     167   -.0339706    .3632613     4.69437   -.7511784    .6832371
FSI_~016 |     167  -1.3882525    .3075984    3.975047   -1.595562   -.3809433
---------+--------------------------------------------------------------------
combined |     334   -.7111115    .2390762    4.369278   -.9814017   -.0408215
---------+--------------------------------------------------------------------
    diff |           1.3542819    .3759995                .8179266    1.890637
------------------------------------------------------------------------------
    diff = mean(FSI_NEW066) - mean(FSI_NEW016)                    t =   3.6018
Ho: diff = 0                                     degrees of freedom =      332

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

```
Variable │     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
─────────┼────────────────────────────────────────────────────────────────────
FSI_~077 │    1905    1.513746    .3017520    .5140845   1.2469346   1.6007347
FSI_~017 │    1905    -.028346    .0117784    2.626187   -.0469346   -.0007347
─────────┼────────────────────────────────────────────────────────────────────
combined │    3810   1.4899114    .0309597    1.910994   1.3842565   1.5956549
─────────┼────────────────────────────────────────────────────────────────────
    diff │           1.5375806    .8613117               1.4577876   1.7173736
─────────┴────────────────────────────────────────────────────────────────────
    diff = mean(FSI_NEW077) - mean(FSI_NEW017)                    t =   1.7852
Ho: diff = 0                                     degrees of freedom =     3808

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

```
Variable │     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
─────────┼────────────────────────────────────────────────────────────────────
FSI_~088 │    2312   1.4218108    .2853374    1.371995    .2658564   1.5777652
FSI_~018 │    2312   -.3342186    .1808759    3.888777   -.1756217   -.4928155
─────────┼────────────────────────────────────────────────────────────────────
combined │    4624    .5437962    .0428764    2.915592    .2439566    .6120728
─────────┼────────────────────────────────────────────────────────────────────
    diff │           1.7560276    .4857618               -.1805418    .1557263
─────────┴────────────────────────────────────────────────────────────────────
    diff = mean(FSI_NEW088) - mean(FSI_NEW018)                    t =   3.6150
Ho: diff = 0                                     degrees of freedom =     4622

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.5425         Pr(|T| > |t|) = 0.8850          Pr(T > t) = 0.0375
```

A7: SUM OF CONDITIONAL FOOD SECURITY INDEX FOR ADOPTERS

Variable	Observation	Mean	Std.Dev.	Min	Max
FSI_NEW011	4333	-0.547223	4.228744	-20.02839	6.676896
FSI_NEW022	501	0.799797	3.673599	-9.400231	11.19153
FSI_NEW033	2301	-0.000676	4.070755	-15.61724	5.109186
FSI_NEW044	54	-0.2127311	1.201055	-2.476814	3.243199
FSI_NEW055	411	0.4124637	1.260201	-2.502367	4.186047
FSI_NEW066	167	-0.0339706	4.69437	-11.75021	17.18478
FSI_NEW077	1905	1.513746	0.5140845	-2.041188	1.531003
FSI_NEW088	2312	1.4218108	1.571995	-6.823643	3.637465

A8: SUM OF CONDITIONAL FOOD SECURITY INDEX FOR NON-ADOPTERS

Variable	Observation	Mean	Std.Dev.	Min	Max
FSI_NEW011	4333	-0.547223	4.228744	-20.02839	6.676896
FSI_NEW022	501	-0.033277	2.833781	-16.28308	5.988963
FSI_NEW033	2301	0.494098	5.321865	-19.64933	6.670742
FSI_NEW044	54	-0.972503	5.489801	-19.43786	6.084136
FSI_NEW055	411	-0.7528728	5.720107	-19.46585	6.098802
FSI_NEW066	167	-1.3882525	3.975047	-19.45553	5.821393
FSI_NEW077	1905	-0.0238346	2.626187	-18.22116	5.960229
FSI_NEW088	2312	-0.3342186	3.888777	-19.61282	6.556417

A9: COMPARISON OF CONDITIONAL FOOD SECURITY INDEX: EXPECTED ADOPTION EFFECT FOR NON-ADOPTERS

```
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_~021 |    4333   -.5083604    .0561839    3.698333   -.4757003   -.6959986
FSI_~011 |    4333    -.547223    .0642417    4.228744   -.6731696   -.4212764
---------+--------------------------------------------------------------------
combined |    8666   -1.055834    .3431015    4.012374  -1.0351759  -1.4038023
---------+--------------------------------------------------------------------
    diff |              .038862    .1853441               .0257776    1.300367
---------+--------------------------------------------------------------------
    diff = mean(FSI_NEW021) - mean(FSI_NEW011)                    t =    .2097
Ho: diff = 0                                     degrees of freedom =     8664

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

```
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_~031 |    4333   -.6719412    .0485427    3.195346   -.7671097   -.5767728
FSI_~011 |    4333    -.547223    .0642417    4.228744   -.6731696   -.4212764
---------+--------------------------------------------------------------------
combined |    8666   -.6095821     .040263    3.748136   -.6885071   -.5306571
---------+--------------------------------------------------------------------
    diff |           -.1247182    .0805195               -.2825555    .0331191
---------+--------------------------------------------------------------------
    diff = mean(FSI_NEW031) - mean(FSI_NEW011)                    t =  -1.5489
Ho: diff = 0                                     degrees of freedom =     8664

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.0607         Pr(|T| > |t|) = 0.1214          Pr(T > t) = 0.9393
```

```
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_~041 |    4333   -.0664909    .0230345    1.516259   -.1116503   -.0213314
FSI_~011 |    4333    -.547223    .0642417    4.228744   -.6731696   -.4212764
---------+--------------------------------------------------------------------
combined |    8666   -.3068569    .0342188    3.185479    -.373934   -.2397799
---------+--------------------------------------------------------------------
    diff |            .4807321    .0682465                .3469528    .6145115
------------------------------------------------------------------------------
    diff = mean(FSI_NEW041) - mean(FSI_NEW011)                    t =   7.0441
Ho: diff = 0                                     degrees of freedom =     8664

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

```
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_~051 |    4333    .3417828      .01809    1.190784    .3063171    .3772484
FSI_~011 |    4333    -.547223    .0642417    4.228744   -.6731696   -.4212764
---------+--------------------------------------------------------------------
combined |    8666   -.1027201    .0337081    3.137931    -.168796   -.0366443
---------+--------------------------------------------------------------------
    diff |            .8890058    .0667401                .7581793    1.019832
------------------------------------------------------------------------------
    diff = mean(FSI_NEW051) - mean(FSI_NEW011)                    t =  13.3204
Ho: diff = 0                                     degrees of freedom =     8664

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

```
------------------------------------------------------------------------------
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_~061 |    4333    .6858194    .0830451    5.466486    .5230086    .8486303
FSI_~011 |    4333    -.547223    .0642417    4.228744   -.6731696   -.4212764
---------+--------------------------------------------------------------------
combined |    8666    .0692982    .0529095    4.925419    -.034417    .1730135
---------+--------------------------------------------------------------------
    diff |            1.233042    .1049928                1.027232    1.438853
------------------------------------------------------------------------------
    diff = mean(FSI_NEW061) - mean(FSI_NEW011)                    t =  11.7441
Ho: diff = 0                                     degrees of freedom =     8664

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

```
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_~071 |    4333    .7806654    .0108668    .7153114    .4019698    .9593609
FSI_~011 |    4333    -.547223    .0642417    4.228744   -.6731696   -.4212764
---------+--------------------------------------------------------------------
combined |    8666    .2334424    .0326715    3.041436    .1779882    .3499002
---------+--------------------------------------------------------------------
    diff |           1.3278884    .4651543                .8388397   1.5942756
---------+--------------------------------------------------------------------
    diff = mean(FSI_NEW071) - mean(FSI_NEW011)                    t =   2.8547
Ho: diff = 0                                     degrees of freedom =     8664

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```

```
Variable |     Obs        Mean    Std. Err.   Std. Dev.   [95% Conf. Interval]
---------+--------------------------------------------------------------------
FSI_~081 |    4333    .8979905    .0223463    1.470958    .6541803    .9818008
FSI_~011 |    4333    -.547223    .0642417    4.228744   -.6731696   -.4212764
---------+--------------------------------------------------------------------
combined |    8666    .3507675    .0341828    3.182126    .2916227    .4576098
---------+--------------------------------------------------------------------
    diff |           1.4452135    .5680173                .9118835    .7785437
---------+--------------------------------------------------------------------
    diff = mean(FSI_NEW081) - mean(FSI_NEW011)                    t =   2.5443
Ho: diff = 0                                     degrees of freedom =     8664

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 1.0000         Pr(|T| > |t|) = 0.0000          Pr(T > t) = 0.0000
```