

**EFFECTS OF CLIMATE VARIABILITY ON CROP YIELD, INCOME AND
RURAL LABOR DISPLACEMENT IN CENTRAL ETHIOPIA**

PhD DISSERTATION

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JULY 2017

HARAMAYA UNIVERSITY, ETHIOPIA

**Effects of Climate Variability on Crop Yield, Income and Rural Labor
Displacement in Central Ethiopia**

**A Dissertation Submitted to the
School of Agricultural Economics and Agribusiness
Postgraduate Program Directorate**

HARAMAYA UNIVERSITY

**In Partial Fulfillment of the Requirements for the Degree of
DOCTOR OF PHILOSOPHY IN AGRICULTURE
(AGRICULTURAL ECONOMICS)**

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DEDICATION

This manuscript workfully dedicated to my belovedwife, **Worke Gete Alemayehu**, for her immense support and sacrifices in managing the entire household responsibilities.

STATEMENT OF THE AUTHOR

Having my signature below, I declare and affirm that this dissertation is my ownwork. I have followed all ethical principles of the university guideline in the preparation, data collection, data analysis and completion of this dissertation. All scholarly matters that are included in the dissertation got the necessary recognition through citation. I asserted that all sources used in this document are cited and referenced. All the possible and potential efforts made to avoid any plagiarism in the preparation of this thesis.

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BIOGRAPHICAL SKETCH

Arega Shumetie was born in Hulet Eju Enesie district, East Gojjam, Ethiopia on April 29, 1983. He attended his primary education in Tikildengay, and the junior secondary education in Sedie primary and junior secondary school. He continued his high school education in Motta senior secondary school. Arega joined Addis Ababa University, Faculty of Business and Economics in 2002 for attending his undergraduate study and graduated with B.A degree in Economics in 2005. After graduation, the author joined Agarfa Agricultural and Technical Vocational Education and Training (ATVET) College as junior instructor from October 2005 to July 2006. Starting from August 2006 up to January 2008, he was junior Economist of Bale Agricultural Development Enterprise. Arega worked as an Economist for Tendaho Housing Development Project in Afar, Dubti until he joined Haramaya University in October 2008 for attending his post-graduate studies in Agricultural Economics. Arega graduated in June 2010 with MSc. degree in agricultural economics and joined the department of Economics in the aforementioned University as a lecturer up to October 2011/12 and he joined the doctoral program in the same university for his PhD degree in Agricultural Economics.

ACKNOWLEDGEMENTS

My warmest gratitude goes to Prof. Belay Kassa, Dr.Degye Goshu and Dr.Majaliwa Mwanjalalo for their unreserved support in this work starting from the proposal level to the final stage. This work may not be at this stage and would not come into an end without their immense contribution.

Given this, I want to forward my acknowledgement to Haramaya University Material and Finance Department, school of Agricultural Economics and Agribusiness staff members. Similarly, College of Business and Economics has credit for its support in the data collection process.

International relation department and Post Graduate Program of Makerere University could also be acknowledged for facilitating my mobility. In this regard, Dr.David Miftumikiza who facilitated all the necessities in my stay at Makerere University had especial role.

Next to this, I want to forward my thankfulness to Dr. Alelign Ademe, Dr. Bamilaku Tadesse, Dr. Mulugeta Deme, Mr. Molla Alemayehu, Mr. Kassahun Mamo, Mr. Abebe Amibachew, Mr. Masiresha Eskesiaw, Mr. Tadele Mamo, Mr. Habitamu Yesigat and other individuals who supported me in one or the other directions.

All the institutions that participate in Ethiopian Rural Household Survey could also take their credit for sharing invaluable panel data for many researchers including me to do dissertation works.

Last but not the least gratitude is to my wife Mrs. Worke Gete Alemayehu who supported me in many directions and managing our household alone. You are all the light that enables me to the right way.

ACRONYMS AND ABBREVIATIONS

2SLS	Two Stage Least Squares
CSAE	Centre for the Study of African Economies
EDRI	Ethiopian Development Research Institute
ERHS	Ethiopian Rural Household Survey
FAO	Food and Agriculture Organization of the United Nations
FE	Fixed Effects
GLS	Generalized Least Squares
GTP	Growth and Transformation Plan
IFPRI	International Food Policy Research Institute
IOM	International Organization for Migration
IPCC	Intergovernmental Panel on Climate Change
MENA	Middle East and North Africa
MVP	Multivariate Probit
NCDC	National Climatic Data Center
NELMT	New Economics Labor Migration Theory
NMA	National Meteorology Agency
OLS	Ordinary Least Squares
RE	Random Effects
SUR	Seemingly Unrelated Regression
TE	Technical Efficiency
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	United States Environmental Protection Agency

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ABSTRACT

Ethiopian smallholder farmers are the most vulnerable group of society to the effects of climate variability because they have a nature dependent economic system. This study examined the effects of climate variability on five major cereals yield, crop income and rural labor displacement in the central highlands and Arsi grain plough farming systems of Ethiopia. The seven round unbalanced panel data (1994-2009) collected by Ethiopian Rural Household Survey from 15 kebeles of the seven farming systems was the base to use panel data in this study. After managing one round survey in 2014 from six sampled kebeles of the two farming systems the research had eight-round unbalanced panel data (1994-2014). Meteorological data from central observatory of Ethiopia showed that long run trend of cropping season temperature and rainfall of the country showed greater variation with frequent extremes in short periods of interval. The stochastic frontier regression result revealed that inorganic fertilizer and draught power significantly increased cereals yield. Cropping season rainfall and temperature have different effect on yield of the five cereal crops as to the model result. Cropping season temperature increment would increase yield of wheat and barley, while it reduces teff, maize and sorghum yield. Yield of teff and barley would significantly increase if there were cropping season rainfall rise in the study area. GLS regression result revealed that shocks sourced from climate variability significantly reduced smallholders' technical efficiency of producing cereals. Fixed effect regression result disclosed negative and significant effect of climate variability elements including cropping season rainfall, temperature, shocks and rainfall inconsistencies on smallholders' crop income. The model result also indicated positive effect of agricultural inputs such as cropland and draught power on crop income. Smallholders' in the two farming systems had 12.04% probability of adopting the four alternative strategies (changing the sowing time, modern technology, alternative income sources and conservation) at a time. MVP model result showed that covariates including rainfall shortage, distance from the main road and crop price increment were common factors that strongly affect the probability of adopting all the strategies simultaneously. Frequent cropping season rainfall shortage initiated smallholders to adopt strategies related to changing sowing time and alternative income sources. The study also identified that most of the rural migrants were youth who were below 25 years. Instrumented random effect two stage least squares regression result showed that crop income, education, livestock owned, participation in off-farm activities and draught power significantly reduced the proportion of family members who displaced due to climate variability. Any of the parameters that reduce crop income would directly aggravate the labor displacement from the study area. In general, climate variability sourced from rainfall inconsistencies commonly affected the crop production, income and rural labor displacement in the two farming systems of Ethiopia. Crop production inputs like fertilizers should be made easily available for households of the study area to use them as to the standard level to enhance cereals yield. Both material and labor budget should be ready to reduce effect of pest infestation and harvesting season rainfall on smallholders' crop yield and income. Crop yield and income of households could be improved if there is due effort to have consistent moisture availability. Displacement of the rural labor could be reduced if alternative income sources are there to supplement household's main source of income, crop production.

Keywords: Climate variability; Smallholders; Yield; Crop income; Adaptation; Labor displacement

1. INTRODUCTION

1.1. Background of the Study

Scientific findings argued that global land and sea temperatures are warming under the influence of greenhouse gases (Intergovernmental Panel on Climate Change (IPCC), 2007a). Continuous increment of the gas emissions result in global warming that promote sea level rise, rapid breakup of ice sheets, changes in precipitation over land and other unexpected shocks (IPCC, 2014a). Recently, worldwide drought increased in frequency, severity, and duration (Peterson *et al.*, 2013). Extreme weather events like severe storms, floods, droughts and heat waves are becoming more frequent and intense recently (IPCC, 2012). Sushenjit and Emmanuel (2012) argued that climate change could increase the number of extreme temperature and rainfall inconsistencies, and hence climate variability showed an upward trend. Recent estimates indicated that unprecedented climate variability mostly occurs in the tropics and among low-income countries, where the projected climate elements continuously move outside the bounds of historical records (Mora *et al.*, 2013). Evidences showed that in the tropics and sub-tropics crops reached their maximum temperature tolerance, and yields would likely to decrease for each further increment. Droughts during 2000–2001 and 2007–2008 were the worst in the history of Central Asia, and in mountainous regions of the area rainfall is getting heavier with frequent floods wherein projections showed even more changes in the future (Ihtiyor and Aden, 2014).

However, climate variability affects a range of sectors, but agriculture is most sensitive to the problem (Cruz *et al.*, 2007). Since agriculture of developing countries has due connection with the natural system, adverse effects of weather variations are potentially harmful for performance of the entire economy (Sara, 2012). Similarly, Edame *et al.* (2011) argued that climate variability could aggravate risk of frequent crop failure for the rural communities that depend on agriculture in a fragile environment. In connection to this, amount and temporal distribution of crop season rainfall is one critical climatic factor for crop yields (DiFalco, 2011). Unfavorable rainfall and temperature conditions can have devastating impact on farm households if the agriculture is purely dependent on rain (Paul *et al.*, 2012), and successive

variability of the climate elements has an overwhelming effect on smallholders' productivity. Rosenberg *et al.* (2003) evidenced that by 2020, world and African cereal production might be 0.5% and 2-3% less than what it would have been in the absence of climate change and this decline may be higher by 2050 and later.

Climate change and variability affects developed and developing nations differently, wherein the latter ones are suffering from serious and continuous food shortage while developed ones are affected by relatively simple problems (FAO, 2008). Altitude is the main determinant in the distribution as well as stability of cropping season rainfall and temperature (FAO, 1996), which are the most important climatic factors for Ethiopian agriculture. The organization identified that rainfall in Ethiopia is highly correlated with altitude wherein middle and higher levels receive substantially greater rainfalls than the lowlands, except western lowlands where rainfall is intense. There is a significant temperature difference among different parts of the country, wherein highlands in the Central North are becoming cold, but the southeast lowlands become warmer (Temesgen *et al.*, 2008). Alemayehu (2003) identified that temperature and rainfall inconsistency, and soil structure determine moisture availability that further influences crop productivity of the country. The author argued that erratic rainfall especially in the lowlands of the country makes crop production very difficult.

The rain-fed agriculture of Ethiopia plays a central role in the economic performance through being a source about 44% of total GDP (Alemayehu *et al.*, 2012). The crop production sub-sector accounts about 80% of the agricultural GDP. Smallholders cultivate 95% of the cropland and produce 90-95% of cereals, pulses and oilseeds. The five major cereal crops (*teff*, wheat, maize, sorghum, and barley) cover about three-quarters of total cultivated area, and constitute 29% and 14% to the agricultural and total GDP, respectively. Grain crops of the country that include cereals, pulses and oilseeds covered 12.60 million ha (CSA, 2015a). The survey also showed that *teff*, maize, sorghum, wheat and barley covered 24.02%, 16.80%, 14.58%, 13.25% and 7.81% of the cropland, respectively. Agricultural production patterns of the country vary markedly among agro-climatic conditions, due to varying rainfall and overall moisture (Alemayehu *et al.*, 2012). Cereal crop productivity of Ethiopia is still at a low level as compared to other developing countries (CSA, 2015b). Hence, smallholders of

the country try to manipulate different remedial activities to enhance their crop productivity through adopting the ongoing climate variability. Effective adaptation strategies may be demanded to secure well-being in the face of climate variability. Climate adaptation should focus on support for smallholders to build their capacity that facilitate social learning, technology transfer, and innovation (Stainforth *et al.*, 2007). Adaptation is most relevant when it influences decisions that exist irrespective of climate variability, but which have longer-term consequences.

Researchers (Alemayehu *et al.*, 2012; Getnet and Mehrab, 2010) argued that crop production of Ethiopia is relatively more sensitive to climate variability, resulting in subsequent income variation and initiating rural labor migration. Today, more than 105 million individuals are working outside their country of birth due to migration (IOM, 2017). The labor migration in Ethiopia increased from 60,031 individuals in 1999 to 73,919 in 2008 (CSA, 2009). The rural-rural labor migration increased from 38 to 47%, in the same year while the rural-urban migration increased from 24 to 27%. This huge rural labor migration may be sourced from agricultural productivity variation that may be due to climate variability. Each crop production variation could result in income reduction for smallholders in the country. Thus, climate variability could have an indirect effect on rural labor displacement through crop income reduction.

Ethiopian Rural Household Survey (ERHS) classified farming systems of the country into seven categories excluding pastorals and agro-pastorals, which comprised only 10% of the rural population (Dercon and Hoddinott, 2011). ERHS considered the crop production system as a central unit to classify the farming systems. The two adjacent farming systems (Central highland and Arsi/Bale grain plough) were samples considered in this study. They are main producer of cereals that frequently suffer from rainfall inconsistencies and occasionally severe drought. Households in the study area commonly produce cereals without supplementing with perennial or cash crops. Given this, ERHS had consistent panel data from sample households in the two farming systems only. Thus, this study tried to examine effect of climate variability on crop yield, crop income and rural labor migration of smallholders in the two farming systems of Ethiopia.

1.2. Statement of the Problem

Majority of the chronically starved people of the world live in rural areas of developing countries, whose livelihoods depend directly or indirectly on agriculture that is highly affected by climate variability and extreme weather shocks (FAO, 2009b). In many low-income countries especially in the tropics and sub-tropics that are vulnerable to rising temperatures and threatened by decreasing water availability, pressure of climate variation is more severe. Most obviously, climate change and variability has the greatest impact on agriculture dependent countries (Deschenes and Greenstone, 2007) in which the problem worsens living conditions of many smallholders (Edameet *et al.*, 2011). Cline (2007) forecasted that agricultural output of developing and industrialized countries might decline by 20% and 6%, respectively due to climate variability in 2080. Similarly, Lobell *et al.* (2011) argued that crop yields would decline by 10% in 2050 nearly in all Sub-Saharan Africa (SSA) countries. In connection to this, Mathilde and Kubik (2014) identified that climate variability is an important source of risk for rural households of developing countries.

UNDP (2007) reported that climate variability sourced shocks could exacerbate income inequality among countries. Dell *et al.* (2008) had supportive finding wherein a 1⁰c temperature rise in a given year could result in a 1.1% reduction in annual economic growth of poor countries. This indicated that climate variability has significant effect in the short-term fluctuation of developing countries' rain-fed agricultural production. In semi-arid and sub-humid areas, rainfall deficits may dramatically reduce crop yields particularly cereals would show the greatest potential variability (Schlenker and Roberts, 2008). Ringer (2010) argued that cereals yield would decline further within moderate global warming. Historically, the significant crop productivity reduction in the developing world sourced from anomalous low precipitation (Sivakumar *et al.*, 2005). Only a few days of extreme temperature at the flowering stage of crops can drastically reduce yield (Wheeler *et al.*, 2000). These all imply that rural populations of the developing world are more vulnerable since they are highly dependent on nature-governed source of income that is agriculture.

Climate variability is mainly manifested in Ethiopia through rainfall and temperature variation (NMA, 2007) and different parts of the country faced insufficient rainfall and higher temperature. Flood was more of a lowland phenomenon, but it is becoming a common problem to highlands and makes the area less productive currently (Arjan *et al.*, 2011). World Bank (2008) identified that temperature increment is a major climate variability element, which affects crop production of Ethiopia significantly. It is predicted that temperature has been increasing annually at a rate of 0.2°C over the past five decades (Yohannes and Mebiratu, 2009), and this resulted in agricultural production decline. The ongoing moisture variability might result in 33% wheat yield reduction in Ethiopia (Amare, 2015). Report of CSA in 2015 revealed that hailstone, rain shortage and outbreak of pests significantly affected cereal yield of the country. Thus, how strong is the effect of climate variability on cereals yield in the two farming systems of Ethiopia was one issue that this research intended to address.

Successive cropping season temperature increment significantly affects agricultural productivity and farm income (Battisti and Naylor, 2009). The problem has additional effects on rural smallholders' farm income and earning opportunities through its induced effect on crop price. Climatic variations frequently create short-term price fluctuations that may have adverse effect on crop income (Getnet and Mehrab, 2010). Coping capacities of households in the developing world are limited due to lower income diversification in turn sourced from climate variability (Arjan *et al.*, 2011).

Adaptation is a natural or human system to moderate the negative effects of actual or expected climatic factors (IPCC, 2007b). It reduces vulnerability from climate variability (Stern, 2007). This indicates that adaptation aims to mitigate and develop appropriate coping measures to address the negative effects of climate variability on agricultural productivity. Smallholders of the country adopt different strategies from their intrinsic and cultural knowledge mainly to cope up moisture stress. Most agricultural systems have an in-built adaptation capacity but the subsequent climate variability impose new and potentially overwhelming pressures on the existing capacity (Gina *et al.*, 2008). Different constraints may hold back smallholders to adopt potential alternative strategies that would reduce negative effect of climate variability.

Both the direct and induced effect of climate variability on rural income could initiate rural labour displacement to other areas. An increasing number of rural people in Africa have been forced to move and search for a living in towns (Annelet *et al.*, 2004). Climate shocks result in higher probability of migration via reducing agricultural yields (Mathilde and Kubik, 2014). Households exposed to drought conditions are far more likely to send a migrant (Hunter *et al.*, 2011) that may reduce family level effect of the problem. Bascom (1995) had also argued that population mobility intensified by severe stress situations, such as drought and famine that deteriorate rural living conditions. Findings of Annelet *et al.* (2004) similarly revealed that poverty because of drought would end up in rural-urban migration. Climate variability, increasing landlessness and fragmented landholdings push rural labor into seasonal out-migration from farming activities in search of additional income (Getnet and Mehrab, 2010). Although the scale of migration differs, people migrate from rural to rural, urban to urban, rural to urban and urban to rural areas in search of a better thing. De Haan *et al.* (2000) found that poor rural people in Ethiopia tend to migrate more often than relatively rich ones, in contrast to the experience of other rich countries. Significant income variation due to climate variability directly results in looking for compensation mechanisms like migration from their dwelling areas.

Labor movement out of agriculture could have far-reaching effects on agricultural production and smallholder's income in rural areas. Many developing countries suffer from a massive brain drain from rural areas that may reduce the agricultural labor. Obtaining the necessary skill with the required competencies and knowledge to run modern agricultural operations may be a serious problem in most developing countries due to rural labor displacement. The problem would create strong economic consequences having a direct effect on agricultural productivity. How strong is the effect of climate variability on rural labor displacement in central Ethiopia, where agriculture is the dominant actor in the overall performance of the economy? Earlier studies did not clearly identify individual effect of climate variability elements on rural labor displacement in Ethiopia.

Studies done before on the effect of climate variability considered the national economic rather than smallholders at different production periods. Panel data allow better observation

about variation across time and individuals (Hyunchul, 2012). Having all the above, this research adopted panel data to examine effect of climate variability on crop yield and income as well as rural labor displacement of smallholders in central highland and Arsi/Bale grain plough farming systems of the country.

1.3. Objectives of the Study

The general objective of this research was to examine effects of climate variability on crop yield and income of smallholders in central highlands and Arsi/Bale grain plough farming systems of Ethiopia. The specific objectives of the study are to:

1. Assess effect of climate variability on cereal crop yield,
2. Analyze effect of climate variability on rural smallholder's crop income,
3. Identify determinants of smallholder's adaptation strategies to climate variability; and
4. Examine the effects of climate variability on rural labor displacement.

1.4. Significance of the Study

Climate variability is becoming a serious bottleneck for achieving food security in most developing countries especially in SSA wherein rain-fed agriculture constitutes the livelihood base for majority of the rural inhabitants. This study, which investigated the effect of climate variability elements on smallholders' crop production in Ethiopia, would have crucial inputs in formulating national level agricultural policies.

More than 95% of Ethiopian crop production is purely nature governed and managed by smallholders who do not have the capacity to cope up with climate related problems. The study considered the main economic activity of the country, crop production that has great interaction with climate variability. Thus, findings of the study would be important in developing policies related to crop production of the country for enhancing productivity of smallholders that take the lion's share in producing both food and industrial crops.

Ethiopian government planned to have middle-income country by 2025 through green economy base that enhance sustainable use of natural resources. The government developed a

strategy to build a green economy and it is implementing the strategy where the process welcomes research findings either from domestic or international researchers. Thus, any supportive works to this vision and plan would be very crucial for achieving the targeted plan.

Achieving the second Growth and Transformation Plan (GTP II) of the country requires boosting agricultural productivity to lay the foundation of industrialization. Thus, it is important to identify the constraints that impede crop productivity and rural income improvement of the country. Therefore, research works and recommendations related to this plan of the country would be invaluable to achieve the predefined objectives. This study hopes to produce crucial inputs for crop productivity improvement of the country.

Detail investigations are not there about problems that hold back smallholders' crop production improvement, which are main producers of consumable or industrial inputs in most developing nations including Ethiopia. Detail investigations about problems that result in crop production variability and sometimes loss should be beneficial to the main economic agents, smallholders. Climate variability frequently affects smallholders' crop production in Ethiopia, and this study tried to examine how significant is the effect of the problem on smallholders' in the two farming systems.

Many research findings showed that the short-run solution of climate variability is adaptation. Smallholders of the country have different indigenous adaptation strategies, and this study tried to identify determinants of adopting those strategies in the two farming systems. How strong is the effect of climate related covariates on aggravating the current time displacement of the rural labor from one area to others? Thus, critical investigations and recommendations of this research could generate useful inputs for national policy makers in formulating policies and programs to reduce the productive rural labor displacement.

Additionally, the study may also be useful input and best stepping-stone for having further researches at meso or macro level about effect of climate variability on smallholders' productivity, income and labor displacement.

1.5. Scope and Limitations of the Study

National level reports showed that small-scale, rain-fed dependent subsistence farmers produce most of the crops in the country. Smallholder farmers that have lower capacity to cope up with severe problems individually were the focus of this study. Variation in climate elements may affect smallholders' livelihood through reducing agricultural production and incomes. Crop damage may be a serious problem at national, local and individual level since the sub-sector has prominent share in the overall economic performance of the country. Cereals tend to be more sensitive to climate variability than other food crops, which was one reason why this study considered only the five major cereal crops. Cereals not only constitute the major food crops in the country, but also serve as a main source of income for smallholders. Findings of this study emphasized on cereal crops that take the dominant share in the overall crop production.

ERHS categorized Ethiopian farming systems into seven categories including Central Highland, Arsi/Bale Grain plough, Grain-plough complex Highlands, Grain plough complex-Northern Highland, Grain-plough/hoe complex, Sorghum plough/hoe Hararghe and *Enset* growing area (with or without coffee). Since crop production in the last three farming systems intermingled with permanent and cash crops, then vulnerability to climate variability may be lower due to diversification. Given this, Grain-plough complex Highlands and Grain plough complex-Northern Highland farming systems have no consistent data throughout the survey periods of ERHS due to civil war and shifting of sampled smallholders. Thus, this study considered the first two farming systems that were consistently visited in conducting ERHS. Additionally, they are from part of the country where cereal crops produced commonly with the frequent rainfall inconsistency.

Due to inability to get consistent time series data for a long period at smallholder level the study considered unbalanced panel data (1994-2014) collected in different time intervals from smallholders in the sampled *kebele* administrations of the two farming system. Whereby, the research limited its study areas only on the six *kebeles* of the two farming systems that commonly produce sample cereal crops (*teff*, wheat, barley, maize and sorghum). Given this,

the main target of the study was to address interaction of climate variability, and crop yield, income as well as rural labor displacement. Thus, content of the research would be limited only to those areas rather than covering the whole concepts covered by ERHS in the previous seven rounds surveys.

Climate change analysis is a complex process that needs longer period of data and laboratory works to examine its detailed impact on yield. This study had eight round unbalanced panel data that could enable to examine the effect of climate variability on crop yield, income and labor migration but not climate change. Since the study had not laboratory works, it could not reveal effect of CO₂ and solar radiations on crop yield, income, health and other effects on smallholders. Thus, this study had a technical and analytical limitation in this regard.

Technically, it is rational to use balanced panel data to consider all the sample units in all the sample years. Due to dissolution and migration of some households, this study failed to have balanced panel data for the sample households from the two farming systems. Since the focus of the study was crop production sub-sector, then the sample households were only from part of the country in which mixed farming practiced. Thus, the study has limitation of examining households from pastoral and agro-pastoral areas of the country.

1.6. Organization of the Dissertation

The dissertation has six chapters. The first chapter, introduction, covers the background, statement of the problem, objectives, limitations and significance of the study. Review of related works, done before, about concepts like definition of terms, empirical works, and theoretical as well as analytical tools covered in the second part of the work, literature review. The third and fourth part of the dissertation covered research methodology, and results and discussion about the findings. Discussion about method of data collection, source and type, method of data analysis to address the predefined objectives covered in the third part of the dissertation. Conclusions and recommendations from the findings presented in the fifth part. Cited works of different authors from previous works listed in the sixth part of the work, reference.

2. LITERATURE REVIEW

This part of the dissertation reviews the crop season rainfall and temperature trend of the country, empirical studies, theoretical and analytical review, and conceptual framework. Works conducted regarding effect of climate variability on smallholders' crop production, income and family member displacement were reviewed. The empirical review provides a foundation to justify the research problem under study and it could enable formulation of conceptual framework that visualizes relationship of climate variability and smallholders' crop production. The methodological framework section briefly discusses the potential methodologies employed to analyze the data in order to address objectives of the study.

2.1. Definition of Terms

Climate change: It can be identified (using statistical tests) by changes in the mean and/or variability of its elements and that persists for an extended period of more than half a century, typically decades or longer (IPCC, 2007b). Climate change is a long-term continuous change of average weather conditions without going back to the normal value of each element. It is a slow and gradual, but not year-to-year variability within short periods. Thus, this study did not consider this concept due to data limitation.

Climate variability: Variations in the mean value and other statistics like standard deviations of all climate elements (mainly rainfall and temperature) on all temporal and spatial scales beyond that of individual weather events (Fussler and Klein, 2006). It is harder for families and communities to predict the ever-changing, inconsistent weather (Oxfam International, 2010). Climate elements may fluctuate over seasons and yearly above or below a long-term average value. It is possible to capture the problem within short period of observation as compared to climate change. Thus, this research uses the concept of climate variability since the number of sample survey years is not long enough to examine climate change.

Labor displacement: Movement of people from one area to others (rural to urban, rural to rural, urban to urban or urban to rural), either temporarily or permanently is migration. If the movement of labor is due to climate variability, then it could be referred as labor

displacement (ILO, 2012), but not migration. This research referred rural labor displacement if there is movement among members of the household within the previous three years, before the time of data collection. Labor displacement sourced from problems related to climate shocks, production loss, agricultural income, food shortage and/or combination of related problems considered in the data collection. Those parameters were the caliper to disentangle rural labor displacement from other form of migrations.

Adaptation: It involves the action that people take in response to actual changes or anticipating projected variations to reduce adverse impacts posed by climate change (Parry *et al.*, 2005). IPCC (2007b) defined climate change adaptation as “adjustment in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderate harms or exploits beneficial opportunities”. Thus, any of the strategies employed by smallholders to enhance crop production through reducing effect of climate variability were adaptation strategies for this dissertation analysis.

Agricultural household: It is a household when at least one member is engaged in growing crops and/or raising livestock in private or in combination with others (CSA. 2007a). Thus, households that practice mixed farming could be within this domain and the study adopted those definitions in considering smallholders to substitute samples if there is dissolution of earlier sampled ones by ERHS in 2009.

Survey season: It refers the time interval on which the data for this study collected (Appendix Table 1). Few of ERHSs had different survey and production season, and there was recall data collection about previous year production in some of surveys by ERHS.

Production year: It implies the season starting from land preparation to harvesting for each crop. Climate related data of each survey follow the production year to have consistency between the crop production and climate variability elements (Appendix Table 3). The study considered the difference in the production years of each cereal in identifying the respective climate variability elements. This definition was the base to consider climate variability elements (rainfall and temperature) for each cereal crops.

Farming system: It is a resource management strategy to achieve economic and sustained production to meet diverse requirements of a farm household while preserving resources base and maintaining a high level environmental quality (Lal and Miller, 1990). Given this, ERHS considered crop production system of households for the classification of the seven farming systems from which this study selected central highland and Arsi/Bale grain plough.

Technical efficiency (TE): Refers to achievement of the maximum potential output from given amounts of inputs, taking into account physical production relationships (Farrell, 1957). Similarly others such as Hensher (2001) and Hollingsworth (2008) defined TE as producing the maximum amount of output from a given amount of input or alternatively, producing a given output with minimum input quantities. From both definitions, TE is highly related to output and its variation could indirectly indicate that there was output variability.

Climate sourced shocks: Climate variability sourced external shocks resulted in huge economic costs and decreased growth (James *et al.*, 2008). Extreme precipitation causes flooding (Falloon and Betts 2009). Given this, events including flood, frost and drought are elements that sourced from climate variability and considered as climate-sourced shocks in this research.

Rainfall inconsistencies: Changes in the precipitation patterns including onset and harvesting times are indicators of climate variability (Sassi and Cardaci, 2012). Similarly, late onsets, early cessation, rainfall at harvesting season, and consistency in the growing season were elements considered as rainfall inconsistency in this research.

2.2. Climate Variability and its Effect in Ethiopia

Recently, concern has grown worldwide that droughts may be increasing in frequency, severity, and duration given changing climatic conditions that increase probability of shocks (Peterson *et al.*, 2013). As a frequent drought there is widening in the gap between water supply and demand for agriculture, and there has been remarkable production variability in both developing and developed countries (Donald *et al.*, 2014). Among the climatic factors, rainfall variability has a colossal effect on livelihoods of the poor as well as economies of

most African countries (Hellmuth *et al.*, 2007). Drought, in particular, represents one of the most important natural factors contributing to famine in many parts of SSA (Bekele *et al.*, 2014). Between 1971 and 2001 alone, drought affected more people than any other natural disaster in Africa (UNEP/GRED, 2005). The increased frequency of drought observed in eastern Africa over the last 20 years is likely to continue as long as global temperatures successively rise (Williams and Funk, 2011). This posed risks on more than 18 million people in the Horn of Africa alone who frequently faced potential food shortages and starvation.

Osman and Sauerborn (2002) indicated that the second half of the 20th century suffered predominantly from negative rainfall anomalies in summer season wherein the rainfall level was frequently lower than the long run average. Yilma and Ulrich (2004) identified that the corresponding persistent warming of the South Atlantic Ocean over the period approximately from 1986 to 2002 caused rainfall decline in Eastern, South and Southwestern Ethiopia. The authors also identified that drought is the most important climate related disaster in the country, although floods and storms also happen periodically. The serious ones that killed many people and animals were in 1957–58, 1964–65, 1972–73 and 1983–84. El Niño event occurred in 2002 associated with impacts of global climate and extreme drought and result in severe production reduction and starvation in the country (Tagel and Anne, 2013). The problem manifested with lower rainfall in the long rainy season that resulted in huge livestock death due to feed shortage. During the time the rainfall, distribution was very uneven in northern part of Ethiopia. Moreover, climate change would greatly exacerbate weather risks since poverty limits capacity of people to manage risks (Hellmuth *et al.*, 2009).

Annual temperature of Ethiopia has rapidly increased in the last five decades thereby the mean level rose by 1.3⁰C that is 0.28⁰C per decade during 1960-2006 (UNDP, 2008b). World Bank (2008) showed that in the coming 100 years the average temperature of Ethiopia has projected to increase from 23.08⁰C to what it was during 1961-1990 to 26.92⁰C in 2070-2099. Drought frequency has been increasing and proportion of the population affected by the problem increased continuously from 8% in 1975 to 16% in 2003 (Abera, 2010). Ethiopia has experienced at least five major national droughts since 1980, along with a large number of localized droughts (World Bank, 2008). These cycles of drought create poverty traps for many

smallholders, constantly consuming their efforts in building assets and income. About half of all rural households in the country experienced at least one major drought from 1999 to 2004 (Dercon, 2009). Having the rain-fed agriculture rainfall variability stressed the lives and well-being of many rural smallholders in Ethiopia. Smallholders' dependency on rainfall and its erratic patterns largely contributed to the food shortages with which they constantly struggle.

In the famine that lasted for three years from 1983–85, about 400,000 to 500,000 people died (deWaal, 1991). The famine of 2003 in Ethiopia was the worst since the mid-1980s, which led about one fifth of the population without food and tens of thousands died because of starvation and malnutrition (Carter, 2011). Ethiopia has been structurally food deficient since 1980. The food gap rose from 0.75 million tons in 1980 to 5 million tons in 1994, falling to 2.6 million tons in 1996 due to better harvest (Befekadu and Berhanu, 2000). The large food aid (240,000 tons) delivered in 1996 fiscal year suggested that chronic food insecurity afflicts millions of Ethiopians even in the absence of transitory production shocks (Devereux, 2000).

Ethiopia's economy showed an average 10% growth over the past decade, but contracted by more than 3% in 2012 when the El Nino occurred (Zenebe *et al.*, 2011). Ethiopian government combats the drought in 2015 by spending 4 billion *Birr* (\$191 million) for importing of 627,000 metric tons of wheat and 20,000 tons of edible oil. Rainfall shortage from February to May in 2015 production year of the country left more than 10 million people in need of emergency support, and the crisis worsened through September of 2015 year. Totally 15 million people were in need of food aid in 2015, and an extra \$340 million was required for relief efforts (William, 2015) due to the crop season rainfall inconsistency. The annual average grain loss was roughly 462,000 ton from 1994 to 2004. Due to drought crop planting in summer and autumn was disrupted wherein 10%-30% yield reductions recorded in central arid area from 710,000 ha (Zenebe *et al.*, 2011). Frequent drought also affected the quality and yield of grazing grassland, which in turn affected the number and quality of livestock. The negative impacts of future climate change and variability entail serious damage on production of *teff* and wheat, but relatively maize yield will increase in 2050 (Zerihun, 2012).

2.3. Cropping Season Temperature and Rainfall Trend

Long run crop season temperature of Ethiopia exhibited upward movement with the going of time wherein the increment becomes higher after 1950 with greater variability. Its variation was in a constantly increasing trend before 1930, but it showed greater variability after 1950s registering the lowest temperature before 1960s. High temperature level, above 23.00 °C registered in 1953-55, and 1980 after 30 years as well in 1998 after 18 years. After 4 years of registering the highest in 1998, the same level of temperature was registered in 2002-06 for longer duration and 3 years later in 2009. This circumstance indicated that the time gap of registering high temperature was narrowing with the going of time and in recent years; there is consistent increment that creates difficulty on the crop production of the country. Given all the above crop season temperature of the country showed drastic type of increment after 2000 production year and this circumstance may continue even in the future.

Similarly, long run cropping season rainfall of the country showed greater variation especially after 1950s. The rainfall was very low in 1972 and 1987 within 15 years interval, this problem happened in 1995 exactly after 8 years, and the problem happened again at a shorter period interval of only 7 years in 2002. This circumstance showed that frequency of low rainfall becomes shorter recently and this would crop production creates uncertainty in the country.

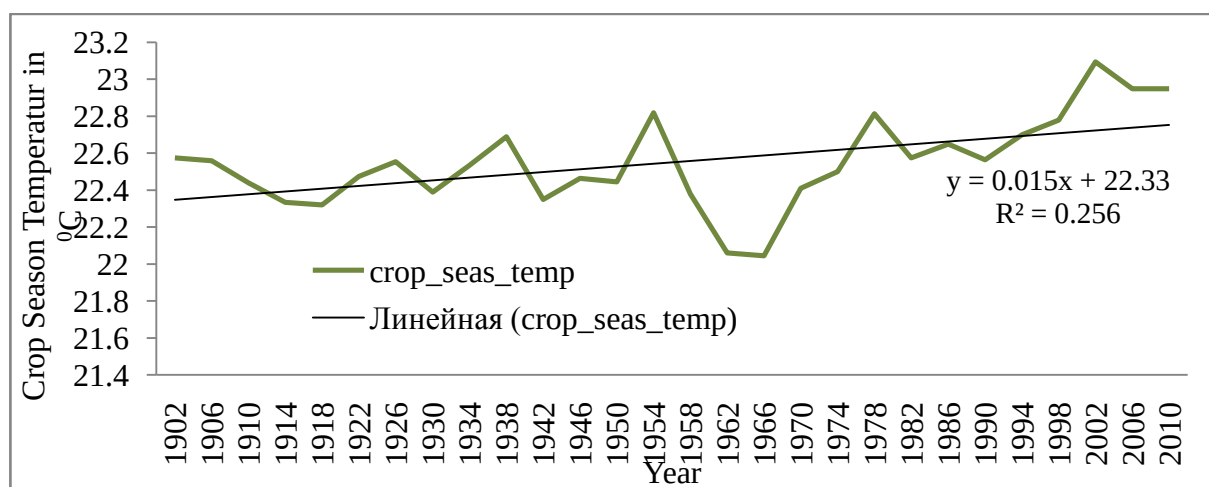


Figure 1. Cropping season temperature trend of Ethiopia.
Source: Ethiopian NMA from the central observatory, 2014.

Though rate of reduction in cropping season rainfall is not like the temperature increment, there was continuous reduction in rainfall of the country. Both variability and reduction of cropping season rainfall were better than the circumstance in temperature. There were subsequent cropping season rainfall variations in many of the production years especially in recent times as to the data collected from central observatory of the country. Cropping season rainfall of the country showed that there was greater variation or volatility in each subsequent production years and the long-run trend exhibited continuous reduction with the going of time and the same condition will continue in the future.

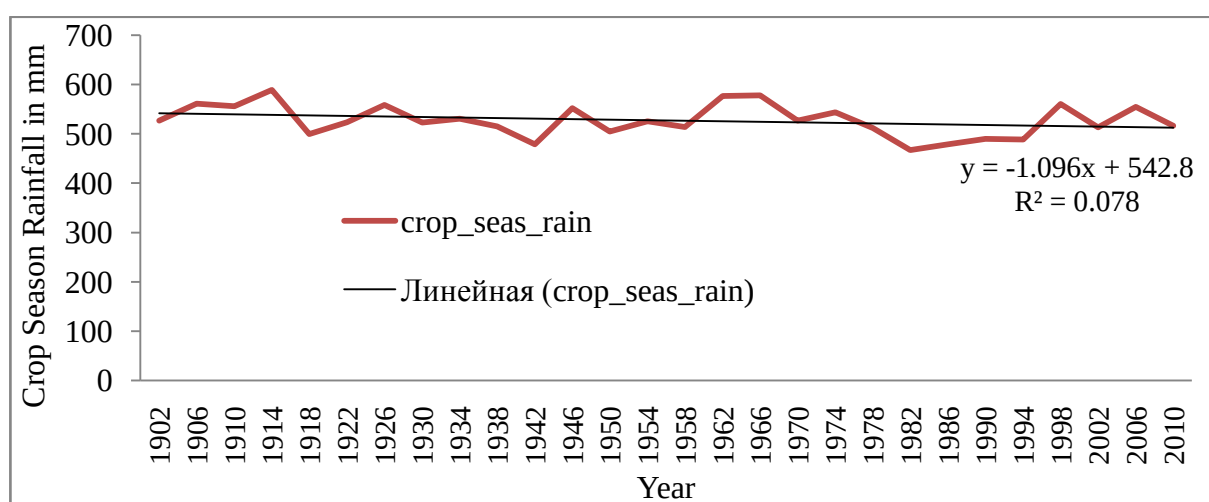


Figure 2. Cropping season rainfall trend of Ethiopia.

Source: Ethiopian NMA from the central observatory, 2014.

Agricultural produce loss due to climate variability may affect the entire economy, given the importance of the sector for employment and livelihoods in many developing countries. Many other economic sectors beyond agriculture would likely experience indirect effects on income and consumption (Zenebe, 2011). Major causes of crop damage in Ethiopia based on response of smallholders were hailstone, flood and weeds (CSA, 2010). About 1.5 million smallholders reported that hailstone was the major cause of damage for all crops followed by high rain wherein 0.12 million smallholders consider it as a major cause of crop damage in 2010. Climate variability is the major risk factor affecting rural livelihood in SSA and rainfall pattern is characterized by large-scale inter-seasonal and inter-annual variability (Abera *et al.*, 2010). Cereal crop damage sourced from frost, high rainfall, pests and disease showed increment from 2006 to 2008 production years as to the report of CSA in 2010.

Table1. Main sources of crop damage in the country

Cause of damage	Number of smallholders in 000							
	2006		2007		2008		2010	
	All crops	Cereals	All crops	Cereals	All crops	Cereals	All crops	Cereals
Floods	231	73	417	166	463	167	70	25
Insects	100	34	84	32	94	30	77	26
Low rain	20	7	17	5	34	9	14	7
High rain	160	46	150	51	201	60	117	35
Hailstone	402	130	236	89	303	99	1,493	654
Pests	50	18	71	33	76	31	37	15

Source: CSA, 2006, 2007, 2008 and 2010.

Since agriculture of the country is a rain-fed type, each variation in one or more elements of the climate would have devastating effect on productivity and income of rural smallholders (Peter and Lamin, 2010). Climate variability mainly encompasses precipitation and temperature, which are the two most important agricultural production inputs (Deschênes and Greenstone, 2007). Since adverse impacts of climate variability are becoming more frequent and severe, the already fragile socioeconomic activity of the country is more likely to exacerbate (Collier *et al.*, 2008). Getnet and Worku (2013) estimated effect of rainfall variability on crop production, and the result showed that if the annual rainfall diverges from its long-term average, thereby production of all crops diminished significantly. The authors also argued that extreme rainfall could reduce productivity effect of fertilizer on crop production, and finally conclude that climate change induced rainfall variability is an inevitable threat to Ethiopian crop production.

Analysis of long-term records of drought events compiled by NMA (1987) over several years in Ethiopia indicated increment in drought frequency at exponential rate. Dejene and Seleshi (2003) showed that there was drought in 1965, 1972–73, 1983–84, 1987–88 and 1997, that resulted in serious agricultural production loss and affected millions of rural poor farmers, pastorals, domestic and wild animals, with sever environmental degradation effect. There is an urgent need to reduce vulnerability of Ethiopia from climate variability and to the threats from the problem (Bekele *et al.*, 2014). The authors also argued that simulation results indicate that, over 50-years period, the projected reduction in agricultural productivity may

result in 30% less average income, compared with the possible outcome in the absence of climate variability. The moisture sufficient highlands of the country are cereal dominate in the crop production and overall productivity is projected to increase approximately until 2030 as a result of climate variability, but the decline could be sharp thereafter. In the high total factor productivity (TFP) growth scenario, overall productivity increment can compensate the loss in other areas where productivity could continuously reduce until 2040, but it could be difficult to keep pace with the loss onwards that year (Zenebe *et al.*, 2011). Those authors also argued that in the low TFP growth scenario, because of climate variability, overall production of both crops and livestock is lower at the end of 2040 than at the beginning. In the drought-prone highlands, land productivity and crop yield expected to decline because of climate variability more or less continuous for most periods, but much of the decline occurs relatively soon.

Rainfall variability has historically been a major cause of food insecurity and famines in the country and the rainfall in Amhara regional state of Ethiopia is characterized by alternation of wet and dry years in a periodic pattern (Woldeamlake, 2009). The author identified that out of the 29 years of observation, 17 years (59%) recorded below the long-term average annual rainfall amount while 12 years recorded above average. Sharp crop production reduction also observed in many parts of the country after 2030 that may increase crop value and actually rises, albeit temporarily, above the no-climate variability baseline (Zenebe *et al.*, 2011).

2.4. Potential Effect of Climate Variability on Crop Income

It is known that climate variability has two contradictory effects on smallholders' crop income: positive (induced) effect through crop price increment and negative (direct) effect via reducing yield. Stephanie (2012) showed that frequent heat waves result in sharp price rises that may increase producers' crop income. Researchers found that climate variability is likely to have far greater influence on crop price volatility than factors that recently blamed for price swings like oil prices, trade policies and government bio-fuel mandates. There was household income reduction for rural farmers of Mozambique, who relies on rain-fed agriculture, when monthly rainfall varies from its normal amounts (Julie and Corene, 2014). Susanne (2012) also argued that regional weather events affected not only price, but also quantity produced that results in net real crop income variation, with a rise of about 84% in 2007 and 18%

reduction after the year. If farmers would have extra produce available for sale, then there may be better crop income collection even with the ongoing climate variability.

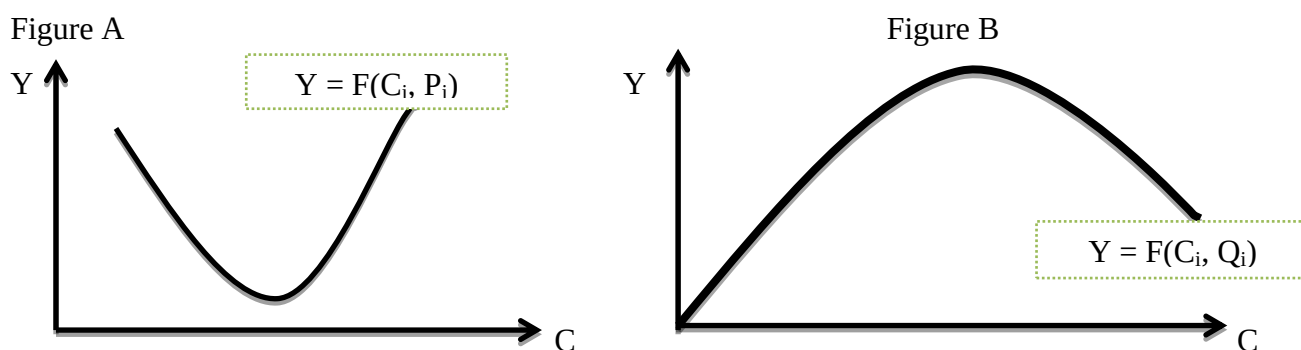


Figure 3. Possible effects of climate variability on crop income

Where: Y =Gross margin

C= Climate variability

P_i = Price of each crop i

Q_i = Quantity of each crop type i

Partial effect of climate variability on crop income takes either of the above two forms. Figure A and B demonstrate relationship between climate variability and crop income through crop price and quantity available for sale variation, respectively. Relationship between crop income and climate variability through price could generate U shaped type of interaction, keeping quantity constant. This logic implies that the lower production due to climate variability could increase crop price as of quantity supply reduction. Inverted U shaped type of relationship between climate variability and crop income could be developed through the quantity effect, keeping price constant. This relationship implies that the quantity of cereals available for sale (marketable amount) would reduce if there were overall production reduction because of climate variability. Since smallholder farmers in Ethiopia have low capacity to produce extra quantity for sale if climate variability affects the crop production, then the problem would have greater negative effect on their crop income because of not having marketable amount. Based on the above figures, the one that has stronger effect would direct overall effect of climate variability on crop income. If the price effect, the positive brunt, outweighs the negative effect via reduction in quantity, then overall effect of climate variability would be positive and improvement in the crop income. In the other direction, if the effect through quantity reduction outweighs, then overall brunt would be negative and each increment in climate variability would result in crop income reduction.

2.5. Theoretical Framework

2.5.1. Determinants of Yield and Income

In the late 18th and early 19th century, the classical economists argued that agriculture does not have the capacity to produce surplus product, but the industry can do that (Jayne *et al.*, 1994). According to growth stages theories, progress in agriculture was dependent on strong export demand or domestic industrial development has the potential to develop agriculture and the total economic growth. Nelson (1981) recognized that there are important interactions between capital formation, labor allocation, technical progress and agricultural productivity. Others argued that technological limitations, rigid social institutions, fragmented markets and reduced communication network between rural areas and urban centers often inhibit the higher level of production (Ferreira and Khatami, 1996). The argument of these authors implies that investment in infrastructure is an important source of agricultural growth. Currently, smallholders hardly aimed at maximizing agricultural productivity and they are just desirous to save their families from starvation due to significant yield variation. They frequently afraid of drought and famine, and sometimes they worried about extensive rains. In this regard, poor peasants tried to utilize the traditional strategies, which they have inherited from their ancestors in order to reduce risks.

Singh and Dhillon (2000) stated that agricultural productivity is frequently associated with the attitude towards work, thrift, industriousness and aspirations for a high standard of living. For the analysis of agricultural productivity functional forms like Linear, Cobb-Douglas, Trans-log, Normalized Quadratic, Leontief and others may be adopted by different researchers. Given those potential functional forms the Cobb-Douglas production function is commonly used because it is theoretically and empirically more plausible as well as being easy to estimate and mathematically manipulate. Smallholders' income mainly derived from farm and non-farm sources (Tessema, 2015) and factors that affect either of the two sources would have significant effect on their overall income. Farm and non-farm activities could play a vital role in the rural economy.

Adoption of better seeds, fertilizers, and simple irrigation devices would enhance staple crops production (Lydia, 2012). In order to boost the crop production fertilizers and other input consumption should be to the standard level, which enable the agriculture sector to earn surplus that may uplift living standard of the majority. The author also argued that one-third of cereal production worldwide increase has been attributed to fertilizer related factors. The transition from subsistence farming to diversified type depends on reasonable and reliable access to credit, fertilizers, water, crop information, and marketing facilities, fair market price for agricultural produce and provision of extensive services. Diversified farming could minimize the impact of staple crop failure, and provide a security of income that was not available earlier.

2.5.2. Theories on Rural Labor Migration

Migration will take place due to the differences in demand for labor in different sectors of the economy (Lewis, 1954), which was the first theory to predict and explain the movement of labor in general terms. However, Lewis's theory soon came under attack from inductive and historical accounts. It became obvious that in many developing countries after World War II there was large scale rural to urban migration, despite huge unemployment in the destination area. Migration continued to flow from labor surplus areas or low wage to areas that had abundant labor and large unemployment.

A new version of neoclassical economic theory developed in the late 1960s in order to explain labor migration, wherein the migrant is a rational actor who calculates the difference between expected and potential earnings as well as the income obtained in the rural sector (Todaro, 1969). Thus, the migrant is an economic agent who decides to migrate based on two main criteria: evaluating the urban-rural real income difference and the probability of obtaining a job in the urban. In this theory, the difference between rural income and potential income from the urban is the factor that gives the rational individual the incentive to migrate. This income difference is the pull factor in the rural labor migration.

Todaro's model and theory is still very influential despite challenged by the New Economics Labor Migration Theory (NELM) after 1980s. The NELM theory explained that migration is a

social groups'- family or household level decision based on how migration transforms the migrant's economy. According to the NELM theory the decision on whether to migrate or not is not necessarily taken by the individual, but the household is more often the basic economic agent that allocates resources (Massey *et al.*, 1993). Moreover, the household may have different motivations and concerns when it makes strategic decisions than the individual family member. It is usually very important to minimize risk, for instance by taking on a diverse portfolio of income generating activities. Since most rural areas in developing countries lack diversified source of income, rural smallholders are vulnerable for seasonal fluctuations and other external risks. Thus, participation in migration may be one way for smallholders to mitigate or reduce risks and uncertainties sourced from climate variability.

In addition to the above human capital theory of labor migration, there are also other recent theories that tried to formulate new versions considering current problems (Wildan, 2012). The network theory of labor migration argued that the network between potential migrants and previous migrants is a significant factor in facilitating the rural migration. Migrants and household members maintain connection and cooperation over long distance through exchange of transfer and other assets. Thus, the complex social network within the community, and prospective migrants and the already migrated ones determined the decision to migrate. Migration sourced from this social factor was not main interest of this study.

However, there are immense theories about rural labor migration, but many of them ignored the current time push factor, climate change and variability, in their discussion. This problem may be critical factor in aggravating rural labor migration especially in developing countries that have rain-fed agriculture as a main source of livelihood for the rural smallholders. Thus, this study tried to incorporate climate variability elements as determinants of rural labor migration in central highland and Arsi grain plough farming systems of Ethiopia.

2.6. Analytical Framework

This section presents the analytical techniques and procedures used in this document. Previous studies done in areas related to this work were investigated to select the appropriate

analytical methodologies to address the predetermined objectives of this study in the two farming systems.

2.6.1. Analytical Framework about Determinants of Crop Yield

Agricultural productivity most commonly estimated using the parametric and non-parametric approaches. In the former approach coefficients of the production function are estimated statistically using econometric approach whereas, in the non-parametric approaches by using the mathematical programming approach. It is the parametric approach commonly used in the estimation of production functions while the non-parametric ones used in efficiency analysis (Coelli *et al.*, 1998).

Production Function Approach, Agronomic-Economic Models (AEM), Agro-Ecological Zone Models (AEZM), and Ricardian Cross-Sectional Model (RCSM) are the prominent models commonly used to assess economic impacts of climate change and variability on agriculture. The Production Function Approach of examining effect of climate variability on agriculture assumes that crops do not have adaptation capacity to the changing climate condition. The model also assumes that land used in a given year for a specific crop would be budgeted for the same crop in other years. In this approach, yields of different crop species are examined under different climatic conditions (Reinsborough, 2003). Considering feature of the experimental design could provide estimates of weather effect on crop yield.

Agronomic-Economic models are biophysical representations of crop production simulating the relevant soil-plant-atmospheric components that determine plant growth and yield. They are tools to examine impacts of climate variability on agricultural productivity, as well as to investigate potential effects of different adaptation options. The AEM employs a controlled experiment on specific crops grown in field or laboratory settings under different climate scenarios such as temperatures, precipitations, and/or CO₂ and others (Adams and McCarl, 2001). AEZM on the contrary assigns crops to agro-ecological zones as indicated in the name and predict their yields. The model relates agro-ecological zones and crop yield variations due to climate variability, which makes it possible to predict effects of alternative climate scenarios on crop yields (Mendelsohn and Dinar, 1999).

Gupta *et al.* (2012) adopted Cobb-Douglas production functional form for investigating effect of climate variability on rice, sorghum and millet productivity using panel data. Precipitation is also a major determinant of crop yield in rain-fed areas. Zaal *et al.* (2004) argued that impact of water supply on crop yields should be estimated using cumulative annual rainfall, but Fermont *et al.* (2009) used growing season rainfall only. Elodie (2012) used two alternative specifications for each crop to avoid multicollinearity. The first analysis, the Temperature–Precipitation (T-P) model, includes the most commonly used weather indicators like precipitation and temperature averages. The model summarized as:

$$Y_{it} = (A_{it}, T_{it}, T_{it}^2, P_{it}, P_{it}^2, T_{it}P_{it}, T_{it}^2, P_{it}, T_{it}P_{it}^2) \quad (1)$$

Where: Y represents yield of crop i at time t,

A is area harvested for each crop i at time t

T and P represent temperature and precipitation, respectively, for each crop i at time t

The second analysis evaluates the effect of temperature including squared term for T_{it} , Standardized Precipitation Index (SPI), drought and flood dummies represent effect of extreme precipitation conditions. The model has the following format:

$$Y_{it} = F(A_{it}, T_{it}, T_{it}^2, SPI_{it}, D_{it}, F_{it}, T_{it}SPI_{it}, T_{it}^2SPI_{it}, T_{it}D_{it}, T_{it}F_{it}) \quad (2)$$

Crop yield determinants like fertilizer, draught power and capital were not considered in the above functional form. Additionally, the formulation may suffer from serious multicollinearity problem due to incorporating interaction and quadratic terms. Although the formulation has immense limitations, it can be used as a base for formulating better analytical framework. It could serve as a base for this research to formulate a mathematical model that is appropriate as to the data type considered. Anthony *et al.* (2011) model yields (Y) using a quadratic function of degree-days d, where d is deviation of temperature from the optimum of each crop.

$$Y = \beta_0 + \beta_1 d^2 + \beta_2 d \quad (3)$$

Where d is the difference between daily temperature or rainfall level, and optimum of the crop. It may be a better formulation in measuring response of the crop at its full growing

period. This method of formulation is difficult in developing nations' agriculture due to serious data problem and difficulty of accessing each plot to have a day-to-day record.

Battese and Coelli,(1992) considered a stochastic frontier production function with a simple exponential specification of time-varying effects, which incorporates unbalanced panel data associated with observations. The model was defined as:

$$\begin{cases} Y_{it} = f(X_{it}; \beta) \exp(V_{it} - U_{it}) \\ \text{and} \\ U_{it} = \eta_{it} U_i = \{\exp[-\eta(t - T)]U_i \end{cases} \quad (4)$$

Where: Y_{it} is the production for individual i at time t .

$f(X_{it}; \beta)$ is suitable functional form of vectors,

X_{it} refers the production inputs and a vector β the unknown parameters

$t=1,2,..n$, the production time considered as a sample

η is an unknown scalar parameter that show reduction, remain constant or increment in the yield variability as t increases, if $\eta > 0$, $\eta = 0$ or $\eta < 0$, respectively.

Battese and Coelli,(1992) and Temperature –Precipitation (T-P) model of Elodie (2012) were the bases to formulate mathematical equations (See section 3.4.1.) in order to examine effect of climate variability on the five cereal crops. The amendment done based on data and crop type as well as smallholder level characteristics of the two farming systems.

2.6.2. Analytical Framework for Determinants of Smallholders' Crop Income

Production Function Approach relies on experimental evidences about effect of climate change and variability on agricultural yields and income (Reinsborough, 2003). Consequently, it is straightforward to use the results of these experiments to estimate impacts of a given change in temperature or precipitation. The approach does not take into account even the short-run adaptation behavior of farmers; it produces estimates of climate change and variability that are downward biased. For this reason, it sometimes referred to as the “dumb-farmer scenario”. This approach may not be logical enough since most smallholder farmers are aware and always try to adopt traditional strategies to increase crop yield and income.

Agronomic-Economic Models (AEM) does not take into account economic considerations that affect actual farm decisions. Estimated changes from experimental crops in agronomic models entered into an economic model to predict crop choice, production, and market prices. One major advantage of this model is that it directly predicts the way climate variability affects crop yields since it requires carefully calibrated controlled experiments. However, it has disadvantages that limits its applicability especially for developing countries since agronomic estimates do not control for adaptation to climate variability (Mendelsohn and Dinar, 1999); and lack of sufficient controlled experiments to determine agronomic responses in developing countries (Seo *et al.*, 2005).

The Agro-Ecological Zone Models (AEZM) are just like the AEM wherein changes in the experimental crops derived from the different agro-ecological zones fed into an economic model to predict overall supply and market effects (Darwin *et al.*, 1995). The greatest strength of this model is its applicability in developing countries if the geographical distribution of zones is available in the region (Mendelsohn *et al.*, 2000). The model is not applicable if climate zones of the country are not clearly identified, and which crop grows in each zone. At the same time, it does not control for adaptation to changing climates as the case with the AEM. Given this, the methodology is not suitable for this study since the data were not agro-ecology based rather farming system.

The Ricardian Model (RM) deeply rooted in the famous theory of economic rents by David Ricardo in 1815 however, much of its application to climate-land value analysis, draws extensively from the work of Mendelsohn *et al.* (1994). The RM simply examines how climate in different places affects the net revenue or value of land. As Seo *et al.* (2005) noted that RM accounts direct impacts of climate on yields of different crops as well as the indirect substitution of different inputs, introduction of different activities, and other potential adaptation by farmers to different climates. Thus, the greatest strength of the model is its ability to incorporate changes that farmers could make to tailor their operations to climate variability to increase potential benefit of cropland. A key assumption to this approach is that land used for a given purpose is best used for that purpose and land values represent the present value of rents when the land is used for its optimal purpose.

The RM method considers temperature and precipitation to examine effect of climate variability on agricultural land value. Mendelsohn *et al.* (1994) examined how climate variability in different places affects net rent or value of farmland. The approach directly measures farm prices or revenues and account direct effect of climate on crop yield, substitution of different inputs, introduction of different activities and other potential adaptation strategies to climate variability. To implement this approach successfully, it is necessary to obtain consistent estimates of the independent influence of climate variability on land values, which requires that all unobserved determinants of land values are orthogonal to climate. Ricardian model bases on the idea that the long-term productivity of land is reflected in its product value. After estimating how climate conditions affect land values or farm net revenues, it is possible to use climate scenarios to infer about effects of climate variability on value and farmland productivity.

Deschenes and Greenstone (2006) link profits and yields to weather fluctuations. Ricardian cross-sectional approaches that measures performance of households and firms across spatial scales with different climates draws heavily on the underlying competitive market assumption of constant prices and land values reflect productivity (Nhemachena *et al.*, 2010). It also assumes that input and output prices are unchanged and that firms adjust their market inputs and outputs to adapt environmental changes. This assumption may be violated in Ethiopian case since our smallholders who produce similar crops may get different prices due to geographic location from the central market. The approach uses monetary values and therefore makes aggregation straight forward (Di Falco, 2011). Despite its few shortcomings, the RM has been extensively applied in different parts of the world with remarkable success (Edame *et al.*, 2011). Since many of its assumptions are in line with Ethiopian smallholders' agriculture, this research employed Ricardian method of analysis to examine effect of climate variability on crop income in the two farming systems. In connection to this, Anthony *et al.* (2011) formulated the economic profit in year t as:

$$Y_{ct} = \alpha_c + \gamma_{st} + X_{ct}\beta + \sum_i \theta_i f_i(W_{ict}) + u_{ct} \quad (5)$$

Where: Y_{ct} is the economic profit that is simply difference between sales and expenditure

α_c is a county fixed effect

γ_{st} is a year fixed effect

X_{ct} are time-varying county-specific control variables like soil quality

W_{ict} is weather variable i in county c at year t .

u_{ct} is the error term.

John and Berhanu (2005) incorporated different input factors (I_f) including labor, ox power, fertilizer, seeds, manure or compost to identify determinants of crop production value per hectare (Y_{hp} = gross revenue function). The gross revenue function includes other covariates like land management practices (M_p), household's endowments of physical capital (K_p) and financial capital (C_a) in the regression.

$$Y_{hp} = Y(I_f, M_p, K_p, C_a, X_v, u_{yhp}) \quad (6)$$

Where: u_{yhp} = random factors

The above functional formulation shows that aggregate produce value per hectare of different crops is a function of both input and non-input factors. Similarly, Kumar and Jyoti (2001) formulated household's revenue (R) by considering climate elements like temperature (T^0), precipitation (P) and deviation of temperature ($DvarT^0$), yearly temperature variation ($YvarT^0$) and capital inputs (K). The authors formulated the following type of mathematical expression to identify effect of climate variability on households' revenue in India.

$$R = F(T^0, P, DvarT^0, YvarT^0, K) \quad (7)$$

James *et al.* (2009) employed a Seemingly Unrelated Regression (SUR) model for the three different sources (Field crops, Horticulture, Animal production) of households' net income in which crop production inputs, wages paid, productivity, temperature and rainfall of each month were considered as explanatory variables for the three equations. The data that this research considered were not long enough to calculate deviation term from the actual level for rainfall and temperature. To calculate temperature and rainfall deviation term it is mandatory to have long run average for each sample *kebele*, which was impossible due to data inconsistency from the national meteorology. Taking the above two functional form as a base this study formulated reduced form of endogenous function (See section 3.4.2.) to examine effect of climate variability on smallholders crop income.

2.6.3. Analytical Methods for Determinants of Labor Migration

Li and Zahniser (2002) adopted probit model to analyze the determinants of temporary rural-urban migration in China. Vera *et al.* (2010) constructed a dummy dependent variable indicating whether the household has at least one member who migrates or not. To consider the magnitude difference of the migrant from each household in the two farming systems this study constructed continuous dependent variable. This type of dependent variable could be able to consider effect of climate variability on the extent of displacement. Different factors like wage gap, income risk, education, gender, family, infrastructure, water resource, cropland and credit access affected labor migration(Wildan, 2012). After listing the potential factors in affecting migration decision, Wildan (2012) formulated two types of mathematical models, which were household and village level type, respectively as:

$$D = F(X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8) \quad (8)$$

The village level mathematical representation considers the percentage of village population going abroad as a dependent variable:

$$Y = F(Z_1, Z_2, Z_3, Z_4, Z_5, Z_6) \quad (9)$$

Agricultural land, socio-economic indicators, access to market and credit, and other covariates include in the village level migration decision framework. The author did not include production inputs in the formulation and did not perceive that income variation is a source of migration. Ikra *et al.* (2011) argued that migration decision is purely dependent on variation of socio-economic (SE) variables. The authors formulated binary probit model to estimate the effects of those covariates on migration decision after having dummy dependent variable.

$$M_i = \beta_0 + \sum_{i=1}^n \beta_i SE_i + \varepsilon_i \quad (10)$$

Shivashankara and Gowda (2010) adopted logit model to identify the determinants of rural-urban migration in India. Underlying the observed dichotomous behavior Y_{it} (whether or not an individual migrates at a given age), there is an unobserved or latent continuous response Y_{it}^* , representing the propensity to migrate (Pau and Amparo, 2016). If the latent response is greater than 0 then the observed response is 1; otherwise it is 0. A linear regression model specified for the latent response Y_{it}^* as:

$$Y_{it}^* = \beta_0 + \beta' X_{it} + u_i \quad (11)$$

This equation tried to show presence of some hazards behind migration decision of individuals, but it failed to consider them in the formulation. Relationship between migration and environment conditions is logical, particularly in rural areas (Nevins, 2007). Environmental and climatic variations affect agricultural productivity and can induce significant migration as a response (Feng *et al.*, 2012). Researchers speculated about peoples' propensity to engage in massive movement from countries that have limited abilities to mitigate environmental hazards. Hunter (2011) employed state level migration model to examine effects of natural disasters and crop yield reduction on the migration likelihood. These all imply that climate variation affects household member's mobility through its effect on yields. Temperature or precipitation shocks could reduce yields and as a result smallholder's income, which in turn induces family members to displace away. The endogeneity problem would direct to employ instrumented model, wherein the first equation generates predicted value of income to use it as an explanatory in the second equation.

$$M_{ij} = f(Y_{farmij}, X_{ij}, C_j) + \varepsilon_{1ij} \quad (12)$$

Where: M_{ij} number of migrants from smallholder i village j

Y_{farmij} is the logarithm of crop income

X_{ij} household level characteristics and

C_j denotes cost of migration, proxy by the distance from the village to a main road

To take into account the endogeneity problem in the first equation, crop income could be instrumented with temperature, precipitation and other determinant variables:

$$Y_{farmij} = f(N_{ij}, L_{ij}, LS_{ij}, S_{ij}, Shock_j) + \varepsilon_{2ij} \quad (13)$$

Smallholder i 's agricultural income is determined as a function of climatic shock in a village j , and as a function of smallholder's number of labor, cropland, livestock units and soil type. Earlier works in connection to migration had a focus on pull and some pushing factors mainly socioeconomic types. The migration analytical framework did not consider effect of climate variability and other production input variations. Thus, this research tried to incorporate climate variability elements in the above mathematical formulation (equation 13) to identify the determinants of rural labor displacement from central highland and Arsi/Bale grain plough farming systems of Ethiopia.

2.7. Empirical Review

2.7.1. Economic Growth Effect of Climate Variability

The global average temperature in 2013 was 14.6⁰c, which was 0.6⁰c warmer than the mid-20th century this adds an evidence for the ongoing climate variability and change (McCarthy, 2014). While the world experienced relatively warm temperature in 2013, but in some countries, it was the hottest year on record. Weather patterns are always causing fluctuations in average temperature from year to year, and the continuous increment in greenhouse gas levels of Earth's atmosphere is driving a long-term global temperature rise. Ihtiyor and Aden (2014) identified huge differences regarding impacts of climate change between large-scale commercial and small-scale farms in the northern regions of Kazakhstan in which the problem had positive income gains effect while the latter affected negatively. The authors also argued that negative impacts could be further aggravated in arid zones of Central Asia due to climate variability and water demand increase in upstream regions if irrigation water availability is not there. Similarly, Parry (2004) argued that impact of climate change on crop yield would be different for countries in developing and developed world. Deschenes and Greenstone (2006) also identified that climate change has a considerable heterogeneous effect on yield of the most important crops produced in some part of USA.

Droughts led to rampant environmental degradation and desertification in most part of the world. With the current level of greenhouse gas emissions, each successive decade will be warmer than the previous one. Inter annual rainfall variability is large over most of Africa, and for some regions multi-decadal variability is substantial (Boko, 2007). Extreme events like droughts and floods have strong population displacement effects on African nations, and prolonged droughts lead to famine, diseases outbreak and deaths in most of the nations.

African countries are likely to be the most vulnerable to climate change since they have limited skills and equipment for disaster management, limited financial resources, weak institutional capacity and heavily dependent on rain-fed agriculture (Rockstrom, 2000). The problem compounded with infertile cropland in most parts of SSA: caused by low production inputs, lack of appropriate technology and lower access to modern inputs (Reardon *et al.*,

1999). Climate change threatens SSA countries to intensify development challenges already confronting them, including food insecurity (Scholes and Biggs, 2004). The recent prolonged and severe droughts, in East African nations like Ethiopia and Kenya, are widely perceived to be symptomatic about effect of changing climate (KMD, 2008). Episodes of recurrent droughts and associated effects on landscape and resources are not new for many of African countries. Abnormal onset of the rainy season results in severe consequences, where abrupt floods destroy infrastructure and hamper physical mobility, damage crop fields, increase disease epidemics for crops and livestock, and have severe impact on livelihoods (Ojwang *et al.*, 2010). Rainfall variability, warmer temperatures and frequency of extreme weather events expected to increase in East Africa and many nations will face risk of longer dry spells and heavier storms. This implies that increased frequency and severity of droughts aggravate aridity of dry lands, making it drier and adversely affecting ecosystems balance, food security and overall livelihoods of communities who depend on rain-fed agriculture.

Climate variability may aggravate the water stress currently faced by some countries in SSA, and some nations that do not experience currently will become at risk in the near future (Imed, 2011). Even without climate variability, several countries in northern Africa will exceed the limits of their economically usable land-based water resources before 2025. About 25% of Africa's population currently experience high water stress, and a number of nations already face semi-arid conditions as of climate change that makes agriculture more challenging, as well as it is likely reducing the length of growing season and forces huge marginal croplands out of production (Boko, 2007). The author also argued that sea-level rise could increase flooding, especially in eastern African coastlines that would have strong health impact. This problem would probably increase the socio-economic and physical vulnerability of coastal cities in the region.

Studies on climate variability identified that the already hot and dry continent, Africa, is most vulnerable to the problem (Mendelsohn and Williams, 2004). The livelihoods and welfare of hundreds of million Africans depend on agriculture (Ojwang *et al.*, 2010) wherein IPCC in 2007b reported confidently that the Middle East and North Africa (MENA) region is extremely vulnerable to climate variations. Majority of the countries in this region belong to

the hydraulic poor part of the world characterized by scarcity and temporal rainfall variability. Moreover, climate change in the MENA is more than an issue of environment rather it is a matter of development. Climate change and variability would further exacerbate economic problems of the region through reducing employment opportunities and food prices hike (Imed, 2011) that would exacerbate the existing poverty and starvation.

Whilst smallholder farmers in some regions of the world may benefit from longer growing seasons and better yields, general consequences of climate variability in Africa, expected to be adverse and particularly for the poor and marginalized farmers that do not have means to withstand shocks and changes (Gina *et al.*, 2008). A recent mapping on vulnerability and poverty in Africa (Orindi *et al.*, 2006) put Ethiopia as one of the most vulnerable nations to climate change with the least capacity to respond. Ethiopia has suffered from periodical extreme climate events, manifested in the form of frequent drought and occasional flooding. Rainfall variability and associated droughts have been major causes of food shortage and famine in Ethiopia. At the national scale, the link between drought and crop production is widely known (Di Falco *et al.*, 2011) in Ethiopian agriculture.

Cline (2008) had argued that global warming is the long list of potential source of risk for world agriculture and it stands out as among the most important. James *et al.* (2008) found that climate variability especially rainfall variation exaggerate food insecurity problem in some part of Zambia due to crop production variation. Raymond (2009) found that projected climate variability over the period 2010-2039 reduces major crop yields by 4.5 to 9% in India. The author also argued that the long-run (2070-2099) impact is dramatic yield reduction by 25% or more in the absence of long-run adaptation. These findings suggest that climate variability is likely to impose significant costs on the economy unless farmers can quickly recognize and adapt to the increasing temperatures. Among several agricultural climate conditions, temperature is the critical factor in deciding the rice cultivation period (Chang-Gil, 2011). In addition, vegetables like onions and lettuce may have problems at high temperatures, which means climate variability not only affects the growth of fruit trees but also their quality, harvest time and storage. Crop production, especially rice, the main food staple, is the most susceptible to climate variability. Any changes in climate will increase rice

production uncertainty in which climate is major cause of year-to-year yield variability. Climate variability not only affects the growth of fruit trees but also their quality, harvest time and storage (Sarker, 2012). Therefore, the change in climatic conditions significantly affects the productivity and quality of crop produces. Increased risk due to global warming has already embedded in agricultural decision-making and uncertainties projected to increase even further (Ihtiyor and Aden, 2014). Effects of climate variability also need to be considered along with other evolving factors that affect agricultural production, such as changes in farming practices and technology for the overall economic improvement.

2.7.2. Effect of Climate Variability on Crop Yield and Income

Global climate change and variability forecasted to decrease global output potential by 6 to 18% from current cultivated lands (Cullen, 2013). However, these forecasts suggest a future widening inequality between countries with favorable agro-climatic conditions and countries whose climates will become increasingly hostile to many food crops. Some food exporting countries at higher latitudes will increase their agricultural production, while many tropical developing countries including major rice exporters will have declining production as to the forecast level (James *et al.*, 2008). The major grain crop supplier to world market, U.S. farmers, faced significant yield reduction due to temperature changes, CO₂, and frequent shocks (USEPA, 2016).

Climate variability mostly affects the rural poor people of developing countries; those that are least able to adopt alternative coping strategies to deal with the problem (Michel and Christopher, 2013). Societies already vulnerable from the problem in some sense more likely challenged disproportionately in which the rural poor arguably affected mostly. Given this, extreme events largely influenced the poor because their agriculture is at risk from frequent floods and droughts, and they have no buffered capital to survive through bad periods. Recent estimates suggested that, relative to the no climate change situation, cereal yields could change by -5 to + 2.5% depending on the region in world.

Wang *et al.* (2008) found that higher temperature to be harmful, and more precipitations to be beneficial for agricultural production. In contrast, their most disaggregated results showed that marginal increases in temperature and rainfall have different effects on agriculture in different regions of the world. Dell *et al.* (2008) argued that extreme weather events always result in significant challenges for local production and livelihoods, but these localized weather events could have global consequences when they strike on the major food-exporting countries and regions. Drought affected areas have become more vulnerable to land degradation, crop damage and livestock deaths due to lack of forage, and in some African countries rain-fed crop yields could be halved by 2020 and net revenues from crops could fall by 90% in 2100 (IPCC, 2007b). Consequently, in the next decade, there might be a haphazard shift in crop growing seasons and poor crop productivity. Smallholder farmers of the arid and semi-arid areas will suffer greater from the emerging climate change related problems (Ojwang *et al.*, 2010). Frequent variability and only few days of extreme temperature at the flowering stage of many crops may result in yield and total factor productivity reduction (Wheeler *et al.*, 2000). The negative and significant effect of maximum growing season temperature may be very harmful to agricultural productivity (Imed, 2011).

By 2020, crop yields in Africa's rain-fed production would decrease by 50% (Boko *et al.*, 2007). Climate variability directly affects agricultural production, since the sector is inherently sensitive to climate conditions and it is the most vulnerable sectors to the risks and impacts of this global problem (Ziervogel *et al.*, 2006). Limited amount and uneven distribution of rainfall is the most limiting factor for crop production and livestock management that could finally has consequences on the wellbeing of the rural populations. Ethiopia is vulnerable to climate variability and change since large segments of its population are poor, dependent on income sources that are highly sensitive to the weather, and have low access to education, information, technology, and health services (Oxfam International, 2010).

Lobell *et al.* (2011) showed that water availability reduction during growing period could have significant effect on reducing agricultural productivity. Indeed, water is vital to plant growth and historically, many of the largest falls in crop productivity have been attributed to sudden reduction of precipitation (Imed, 2011). Moreover, uncertainty about agricultural

production will increase as extreme climate events like droughts and floods are more frequent. The uncertain production environment is pervasive in its effect on farming practices and farm performance that could discourage smallholders in adopting new production technologies. This indicates that climate variability and change has an induced effect on smallholder's performance and futurity.

Temperature increment from 1 to 3°C is expected to benefit crop and pasture yields in temperate regions, while in tropical and seasonally dry regions it is likely to have negative impacts, particularly for cereal crops (Leff *et al.*, 2004). More than 3°C increment expected to have negative effects on production in all regions of the world (IPCC, 2007b). The report also showed that meat and other livestock products supply will be influenced by crop production trends since feed crops account for roughly 25% of the world's cropland. When temperature was 6°C above the long-term mean, crop yields dropped significantly for instance 36% for maize in Italy, and 25% for fruit and 30% for forage in France (Porter and Semenov, 2005). The authors also indicated that frequent storms that altered the precipitation have long-run implications on the viability of current world agro-ecosystems and future food availability.

A 2°C local warming in the mid-latitudes could increase wheat production by nearly 10% whereas at low latitudes the same amount of temperature increment may decrease yields by nearly the same amount (Jemma *et al.*, 2010). This indicates that income of small-scale farmers in developing countries would decline sharply since performance of the crop production sub-sector declined significantly. Climate extreme events affected availability of certain food products, which may influence price that could have an indirect effect on income. Short-term yield fluctuations for smallholders related to the national level variation because of climate variability. In arid and tropical regions where temperature is already close to physiological maxima for crops, further temperature increment may be more detrimental that increase the heat stress on crops. Lobell *et al.* (2008) estimated that warming since 1981 resulted in global level losses of 40 million tons from production of wheat, maize and barley due to high temperature. Several villages in Tigray and Southern Nations and Nationality Peoplregional states of Ethiopia experienced severe localized droughts that caused considerable income losses (Dercon *et al.*, 2009)

2.7.3. Smallholder's Adaptation Strategies to Climate Variability

Traditional adaptation strategies to climate change and variability in Uganda include diversification of resource base and participating in non-farming activities (Bagamba, *et al.*, 2012). Most farmers in central region are engaged in off-farm self-employment and they are least affected by climate variability while many farmers in the southwest of Uganda derive their livelihood from farming (Bagamba, 2007). Diversification into other activities, specifically non-farm, could be one means used by smallholders to cope with environmental problems (Soini, 2005).

Agrawal and Perrin (2008) identified that strategies like seed selection, changing planting dates, fertilizer application, and food storage facilities improvement as an adaptive mechanism employed by smallholders to cope up with climate variability. Smallholders also adopt water management techniques such as water harvesting, rehabilitate terraces and improve irrigation techniques to cope with rainfall variability. To diversify income smallholder's adopted techniques including temporal or permanent migration, use of alternative sources of fuel wood, home-garden agriculture, changes in the consumption pattern or reductions of livestock herd, reforestation, rangeland preservation, communal food storage facilities or local water management rules (Arjan *et al.*, 2011).

Individual water harvesting techniques are more common in Yemen than in Ethiopia where the techniques currently promoted by the extension programs (Arjan *et al.*, 2011). Households of the two nations switch to crops that are more drought resistant in recent times. Most Malian households, especially those in the Sahelian regions, already have switched from sorghum to the more drought resistant Millet. In Ethiopia, more effort is exerted on solving the problem of deforestation, which is an institution-based strategy where individual households could not easily adopt and requires presence of effective institutions. Malians mostly selected individual strategies, while in Ethiopia and Yemen there is a mixing of individual and communal strategies (Arjan *et al.*, 2011), which shows the main strategies adopted according to the communal versus individual characteristics and coping capacity enhancement.

Institutions play an important role in improving livelihoods in Ethiopia through implementing communal adaptation strategies (Bryan *et al.*, 2009). Findings of this study were similar to work of Temesgen *et al.* (2008). However, some of the adaptation strategies employed tended to have a backlash for instance some rural poor have been compelled to sell their assets in an attempt to cope with the food insecurity brought by climate variability. Crop diversification has proven to be successful in Bikita with a number of respondents highlighting that they have moved to new crop varieties that are relatively drought resistant and hence can withstand the long dry spells that are rampant (Gukurume, 2011). Adoption of small drought resistant crops as if sorghum and millet have become the most dominant crops in the area and the rationale behind was their adaptability to both climate variability and poor soil nutrients. Traditional and indigenous knowledge systems have also been extremely useful in both adaptation and mitigation strategies devised by the smallholders in most parts of the world.

Wealthier households in Ethiopia participated more in communal strategies, like soil and water conservation, for which external help is necessary (Arjan, 2011). In many cases, adaptation activities are local, district, regional or national issues rather than being an international concern (Paavola and Adger, 2005). New cropping systems such as zero tillage as well as minimum tillage or conservation farming have been widely introduced by various stakeholders in order to adapt climate variability especially in the tropics. Strengthening agricultural production systems is a fundamental means of improving incomes and food security for the food insecure part of the world (Ravallion and Chen, 2007). Improving the resilience of agricultural systems is essential for climate change adaptation and it is the key economic sector of most low-income countries (Conant, 2009) especially in the short run. Works done before indicated that smallholders in different parts of the world have their own indigenous adaptation strategies to reduce effects of climate change and variability.

2.7.4. Climate Variability and Rural Labor Displacement

A study done by Harris and Todaro in 1970 argued that rural migration is based on the expected wage disparities between the rural and urban formal labor markets as a driving force behind the decision to migrate. It is a response to changes in living cost, as well as to the evolution of real wage differentials in factors of production. They argued that capital

accumulation and competition between sectors are the drivers of rural-urban labor migration. The pull factors in the urban took the significant effect in the rural labor migration as to the previous theories. Prior works showed that migration is associated with local economic conditions that are particularly indicative of opportunities for remunerated work for labor (Riosmena, 2009). Major driving forces of internal and international migration are different in expected earnings between rural and urban locations, family strategies to cope with the risk of agriculture, and relative deprivation. Empirically, differences in expected earnings between agricultural and industrial occupations seem to be key drivers of rural to urban migration. However, the current situation is not going in this direction, but many theorists argued that rural-urban migration has long been associated with economic development and growth. Given this, the recent phenomenon may be different due to complex push factors in the rural economy.

One would expect climatic variability to have an impact on international migration, particularly in drier places (Durand and Massey, 2003). The impacts of climate change and variability via different directions push around 600 million people into malnutrition and increase the number of people facing water scarcity by 1.8 billion in 2080 (UNDP, 2008a), which all would be pushed to displace from their original places. Thus, population displacement would be aggravated, as people become squatters or rely on relief aid, sometimes forced to live in abject poverty. Migration that may decrease vulnerability would likely to continue to increase in the future (Mertz, 2011). The decision to migrate may be to escape from an environment that no longer felt to guarantee survival. Drought, crop failure and famine would result in distress migration (Michel and Christopher, 2013). Over the last 50 years, 800 million people have migrated from rural to urban areas (Riosmena, 2009). Lack of decent work combined with widening disparities in incomes and human security were main push factors in rural areas. Cropland degradation, agricultural productivity reduction, lack of access to credit and arable land, and shifting the farmland into capital intensive industries contribute to rural out migration (ILO, 2012). Migration can disrupt local employment, undermine family and community cohesion, and engender dangerous and exploitative working conditions.

The desire to improve the conditions in their villages led rural people to migrate to towns temporarily in pursuit of cash (Potts, 2008). Rural people move to urban areas in search of better paying jobs and amenities, such as better schools, health care, and entertainment centers, but the urban economies are unable to absorb most rural migrants, particularly those with low education. Migration can alleviate pressures on local labor markets, land and natural resources, but it may also create labor shortages in rural communities that reduce smallholders' productivity and exacerbate child labor exploitation. The huge rural out-migration may exert pressure on urban labor markets as well as quality of life mostly in the developing world. Environmental degradation and climate change accelerate displacement of rural populations who would otherwise prefer to stay in their place of origin. A large number of rural-urban migrants remain jobless and eventually return to rural areas and engaged in their farming (Potts, 2008). Ezra and Kiros (2001) evidenced that environmentally induced migration has been found to be significant for low-income countries like Ethiopia.

2.7.5. Effect of Rural Labor Migration on Agriculture

Whereas initial theories effectively suggested that migration took place primarily if migrants could obtain higher returns to their human capital, theories that are more recent suggest that migration may also arise as part of a smallholder strategy to overcome other constraints (Lucas and Stark, 1985). The logic behind this argument is labor migration may be performed to enhance the agriculture through backward linkage through remittance and cash flow. In such an environment, individual participation in migration arises so that it can make investments in its farm or non-farm income generating activities. Migration may reduce poverty through increased returns to labor for the migrant and remittance to the source household. Though migration should be poverty reducing, its relationship with agricultural production at the household level may be complex (Alan, 2014).

In densely populated regions of the world, outmigration of rural labor may be a way to alleviate underemployment in agriculture and protect the farmers' livelihoods (International Fund for Agricultural Development (IFAD), 2007). This logic implies that seasonal migration allows for a better deployment of labor, since those who are underemployed during the agricultural lean season can find work in towns or in other areas, thereby increasing their

incomes. The migrant individual may use the money received from migration to invest in an investment back home. During the green revolution in India, diaspora members supported the acquisition of nearly 2000 tractors and tube wells thanks to government incentives. They support the shift to modern farming such as ‘zero grazing’ forms of livestock and horticulture and the development of non-farm activities. Some seasonal emigrants may use the skills and farming techniques learnt abroad to improve their activity. In countries where land purchase and farm investment still attracts a fair amount of migrants’ investments, farm revenue is significantly higher for migrant than for non-migrant households (Thomas, 2012).

Migration may enhance smallholders’ agricultural output through remittances reinvestment. This reinvested remittance may compensate the reduction of farm labor due to migration and the loss in output. Policies facilitating migration, the flow of remittances, and their use for farm investment may contribute to reduce poverty, increased agricultural output, and decrease income uncertainty. Rural to urban migration is typical for economies in transition from an agricultural structure to an industrial and services economy (Huynh and Walter, 2015). Migration of farm household members, especially those with small farmland and low productivity may have net positive effects on agricultural output, if there is reinvestment of remittances. Up scaling small farms, making use of increasing returns to scale in agricultural production, tends to have larger effects on agricultural output, contributing to efficiency and reduction of poverty. Promoting measures to reinvest remittances in farm up scaling are policies that support not farm income vulnerability but also agricultural output and efficiency.

Other scholars including Michel and Christopher (2013) argued that rural-urban migration, in the absence of technological progress in agriculture, would result in total agricultural output reduction. On the other hand, more lasting outmigration can deprive rural areas of critical agricultural labor during farming seasons (Deshingkar and Grimm, 2005). Outmigration can also cause the drain of skills and the loss of innovative community members from rural areas. Migration has a direct impact on the available household labor for agricultural production, so that there is a case for reverse causation between agricultural output and household member migration (Huynh and Walter, 2012).

2.8. Conceptual Framework

Climate change is posing the greatest threat on agriculture and food security in the 21st century, particularly for many of the poor and agriculture-based countries of SSA (Nellemann *et al.*, 2009). The problem increases water scarcity (Lobell *et al.*, 2009) and temperature increment (Jon *et al.*, 2012). Growing season temperatures will exceed the extreme seasonal level record in the past century (Battisti and Naylor, 2009). Global warming has significant impacts on inputs that affect agriculture through changing temperature, CO₂, glacial run-off, precipitation and interaction of these elements. The World Bank (2007) identified five main factors through which climate change affected the crop productivity: changes in precipitation, temperature, carbon dioxide (CO₂), fertilization, climate variability, and surface water runoff.

There will be intensification of global frequency and severity of drought if climate change continues, and some regions adversely affected by the change in rainfall patterns, rising temperatures and severe drought (John, 2008). These conditions determine the carrying capacity of the biosphere to produce enough food for the human population and domesticated animals (Schneider, 2007). In general, climate change and variability could result in droughts, heat waves, floods and rainfall variation, and push millions into malnutrition and extreme poverty (UNDP, 2008a).

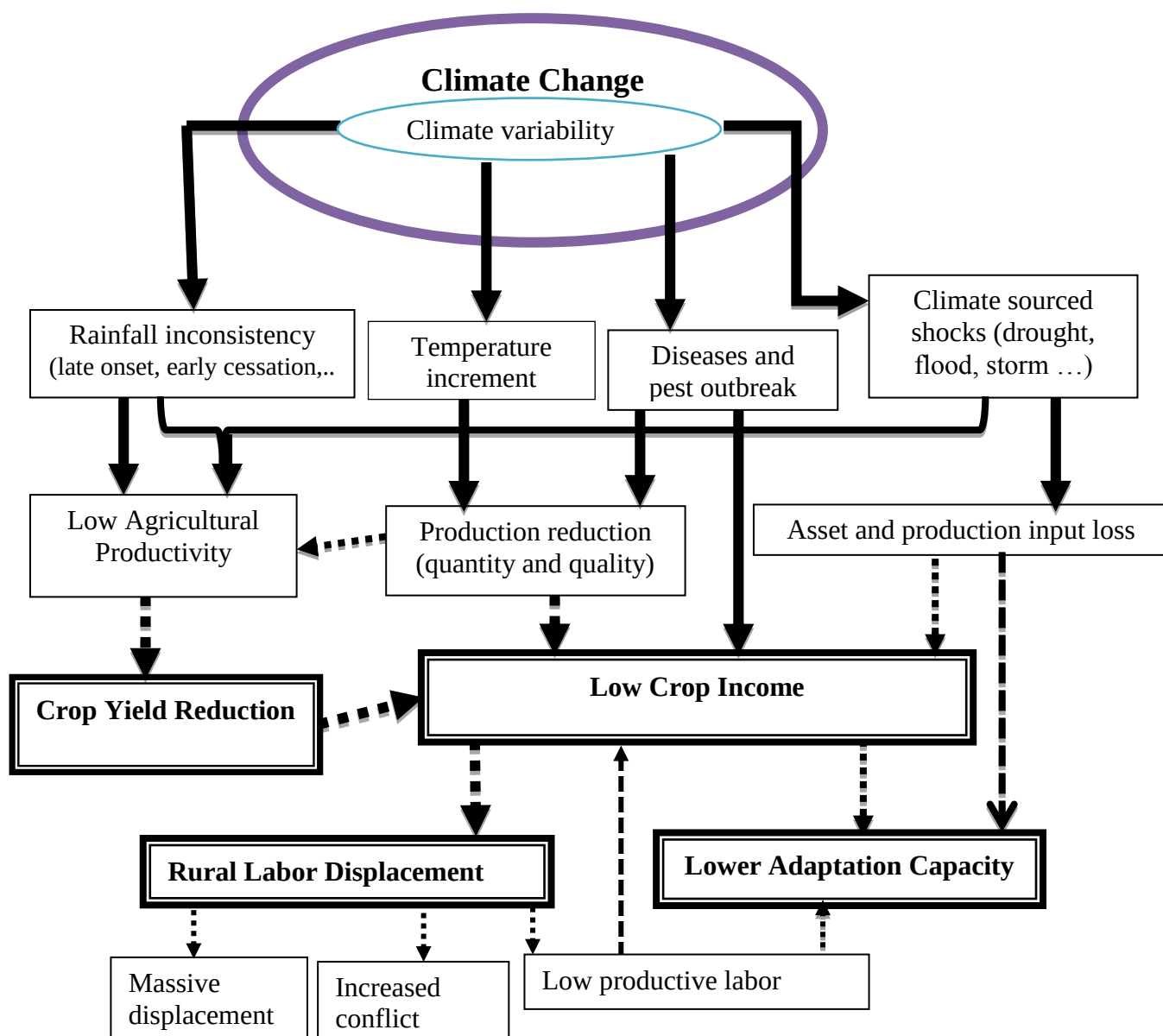
Crop production is directly influenced by precipitation and temperature (Schultz *et al.*, 2011). Weather variability has significant influence on crop yields (Lobell *et al.*, 2011), which indicates that variation in the day-to-day weather conditions could affect the crop production process. Changes in rainfall patterns and droughts increase the likelihood of short-run crop failures and long-run production declines causing food insecurity (Nnyaladzi, 2012). The author also noted that the drier the climate, the greater the rainfall variability and yield instability. Soil moisture deficits, crop damage and disease outbreak are all driven from rainfall and moisture variability (Eva, 2009). Higher temperatures and humidity could increase the probability of insects and disease outbreak (Schneider, 2007). Over time, these complexes and interacting factors induce a strong effect on agriculture especially on the crop production (John, 2009). Approximately 40% of SSA countries are at risk of significant crop

production reduction due to climate variability (Shah *et al.*, 2008). Droughts seriously affect agricultural yields and can contribute to spikes on income through price (John, 2008).

Strong negative rainfall anomalies frequently lead to yield variation often associated with small rainfall anomalies (Liqiang, 2005). Martin (2007) found that world cereal production would decrease between 1 and 7% depending on the climate scenario of the world. The higher temperatures sourced from climate variability would force plants to lose their moisture (Cline, 2008). Beyond a certain range of temperatures, warming tends to reduce crop yields because of moisture loss in their development, and finally produce less grain. Thus, climate variability affects food production directly through changing environmental conditions (Eva, 2009) and the problem indirectly affects growth and distribution of rural incomes. The environment affects consumption mainly through its impacts on current agricultural production and/or income. This logic could hold true for rural areas where crop production is purely dependent on nature sourced precipitation and temperature.

Climate variability in rural areas of developing countries is the major threat to smallholders' income and therefore acts as a push factor in initiating rural migration (Jonas and Heiko, 2010). Findings of Mathilde and Zaneta (2014) confirmed that climate shocks could significantly increase the probability of rural migration through reducing agricultural yields. Those authors identified that a 1% agricultural income reduction induced by weather shock could increase the probability of rural labor migration by 3%. Ezra and Kiros (2001), and Henry *et al.* (2004) argued that rural labor migration in low-income countries is environmentally induced type.

Detailed investigation of all the above empirical works were the base for developing the conceptual framework here in this study to examine the effect of climate variability on crop yield, income and rural labor displacement in central highland and Arsi grain plough farming systems of Ethiopia.



Note: The solid arrows show direct relationship of climate variability elements to the economic activities while the dashed ones show indirect.

Source: Own development based on empirical works

Figure 4. Conceptual framework

3. RESEARCH METHODOLOGY

This chapter provides details of the methodology used to address the predefined objectives of the study. It includes description of the study area, sampling design, type of data and method of collection, methods of data analyses and description of the covariates for each model.

3.1. Description of the Study Area and Data Source

Ethiopia has seven farming systems, excluding pastorals and agro-pastorals, according to ERHS classification. The farming systems include Grain plough complex (Central highland), Arsi/Bale (here after Arsi) grain plough, Grain-plough complex highlands (Wollo area), Grain plough complex highlands (Northern highland (Tigray)), Grain-plough/hoe complex, Sorghum plough/hoe Hararghe and *Enset* growing (with or without coffee/cereals). The survey considered the main crop type produced, the way of cultivation, land utilization as well as other features of smallholders in categorizing farming systems of the country. Different institutions like International Food Policy Research Institute (IFPRI), Centre for the Study of African Economies (CSAE) at Oxford University, Economics Department of Addis Ababa University and Ethiopian Development Research Institute (EDRI) participated in ERHS conducted on the seven farming systems of the country. ERHS started in 1989 when IFPRI team visited 450 households from seven rural *kebeles* in Central highlands and Southern Ethiopia (Dercon and Hoddinot, 2004). In 1994, the survey extended to 15 *kebeles* to cover the main farming systems of the country. Sampled households were randomly selected from each *kebele* through stratification techniques in order to have sufficient coverage from each farming system. Totally 1,477 households were included in 1994a¹ survey. These households were re-interviewed in 1994b as well as in 1995, 1997, 1999, 2004 and 2009 (Dercon and Hoddinot, 2011).

The first two farming systems (central highlands and Arsi grain plough) were samples considered in this research because of high concentration of cereal crops; consistent panel data availability and relatively more vulnerable from climate variability problems. These two

¹ There were two surveys in 1994 and the first one named as 1994a and the second as 1994b

farming systems took 43.3% of sampling share of the well-organized survey of ERHS in 1994 (Dercon and Hoddinott, 2011). At the same time, they accounted 58% of the consistent panel sampled smallholders of the successive surveys after 1994. Those authors also claimed that the two farming systems covered 40% of the national population based on CSA in 1994. Given all the above, this study considered the six *kebeles* (Table 2) and 581 households for the eighth round survey in 2014 from central highland and Arsi grain plough farming systems.

Table 2. Main crops produced and agro-ecological description of sample *kebeles*

Name of <i>kebele</i>	Location	Main crops grown	Rainfall* (mm)	Elevation (m a.s.l)	Agro-ecology
Debre-Berhan	North Shoa	Wheat, barley, beans	903	2750	<i>Dega</i>
Yetmen	Gojjam	<i>Teff</i> , maize, wheat	1384	2418	<i>Weyna-dega</i>
Dinki	North Shoa	<i>Teff</i> , maize, sorghum	1190	1805	<i>Kola</i>
Sirbana-Godeti	Central Shoa	<i>Teff</i> , maize, wheat, barley	993	1900	<i>Weyna-dega</i>
Korodegaga	Arsi	<i>Teff</i> , maize, wheat	739	1351	<i>Kola</i>
Turufe-Kechemane	Arsi	<i>Teff</i> , wheat, barley	879	1937	<i>Weyna-dega</i>

Note: * Annual average rainfall from 1991-2013 organized by NMA (2014)

Source: ERHS, 2009

The first four *kebeles* in the above table are from central highlands and the last two from Arsi grain plough farming system of Ethiopia. All sample *kebeles* have two rainy seasons, spring (*Belg*) and summer (*Kiremit*), the latter being the main rainy season lasting from June to September and the former continues from March to May. Households in the sample *kebeles* practiced mixed farming to produce cereal and other crops like pulses, and cash crops. Some of the *kebeles* (Dinki and Korodegaga) severely affected by drought in few production years (Dercon and Hoddinott, 2011). The following figure shows that sample *kebeles* in the study from the two farming systems covered the central and mostly highland parts of the country. It is the area wherein dominant cereals including *teff*, wheat, barley, maize and sorghum commonly produced.

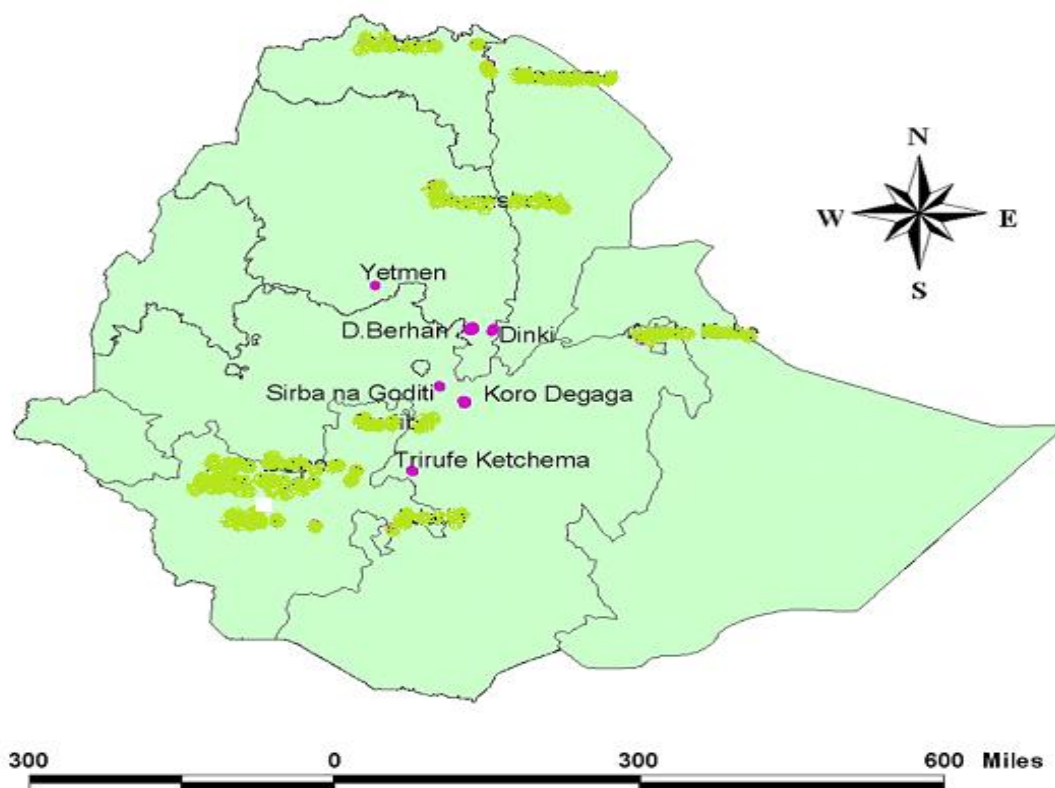


Figure 5. Geographical location of sample *kebeles*

Source: Dercon and Hoddinot, 2011

3.2. Sampling Unit and Design

Sample selection of this study was not a big deal since it is based on secondary data generated by ERHS. ERHS considered the crop production system as an important stratification basis than administrative boundaries in selecting the final sample units, smallholders. This study simply considered all sample *kebeles* as well as households from the two farming systems (Central highland and Arsi grain plough) included in the data collection of the last ERHS in 2009. Sample households selected randomly were proportional to the total households within each *kebele*. The sample size from each *kebele* was representative since each individual household was selected considering the proportions from the total population. Each survey followed a similar format of sample units that were already determined in the first well-organized survey of 1994a. Sample proportions from each *kebele*, considered in the last survey (2009) of ERHS, directly accepted by this research to have the eighth round survey in 2014. The study tried to revisit all the sampled households (581) from the six *kebeles* in 2014 survey and the data collected from the 575 households having 1.03% iteration.

Table 3. Sample distribution in each *kebele*

<i>Kebele</i> name	No of households in 2009	No of households in 2014	Percentage in 2014	Farming system
D/Birhan	168	166	28.87	Central highland
Yetmen	51	50	8.70	Central highland
Dinki	79	78	13.56	Central highland
Sirbana	82	82	14.26	Central highland
Koro	106	104	18.09	Arsi grain plough
Turufe	95	95	16.52	Arsi grain plough
Total	581	575	100	

Source: Dercon and Hoddinott, 2011.

This research considered households who were not retired or those who were economically active for practicing mixed farming. New households included as a sample in case of dissolution of sampled households after 2009 to have representative sample size. In this case, an exact proportion of newly households that have similarity in demographic and wealth terms replaced the lost ones. Village elders and officials were consulted to evaluate similarity of the new households with the lost ones. When attrition is exogenous, that is unrelated with the response variable *Y*, the information carried by the sample could be unbiased about the population level regression function of *Y* (Franco, 2001). This is no longer true when attrition is endogenous, that is if the information is systematically related to *Y* (the respondent itself), in this case attrition could typically be important. Attrition in using panel data could result in serious problem if the main objective of the study is related to the respondents characteristics: going to college, finding a job, marriage, death and the like. In this situation, attrition may result in invalid inference about the population of interest, even if the attrition rate is modest. Since each of the predefined objective of this research were not related to personal characteristics of the respondent, modest attrition rate in the sampling process is not expected to generate biased conclusions and recommendations. Given this, the attrition rate in ERHS was very small that was 1% on average for each survey.

3.3. Types and Methods of Data Collection

This work considered both primary and secondary data, in which the former ones were collected from sampled smallholders of each *kebele* (Table 2) that are located in the two

farming systems. ERHS collected the data from rural Ethiopia especially from high and mid-land parts where mixed farming practiced commonly. The previous seven round ERHSs (1994a-2009) covered different aspects of smallholders' including demographic, consumption (food and non-food), production, asset holding, purchases and sales, landholdings and livestock ownership and other aspects. Moreover, data on prices, access to health and education as well as infrastructure were collected at community level.

Having the previous seven round surveys (1994a-2009) and the recent one in 2014, the research had eight round unbalanced panel data for sample households from the six *kebeles* only. The eighth round survey from the sample *kebeles* incorporated recent circumstances about sample smallholders. This survey adopted the questionnaire (after amending as to the objective of this research) used by ERHS in collecting the seventh round survey in 2009. In addition to the panel data collected by ERHS and this research, the study also considered other secondary data from different institutions like CSA and NMA.

Ideally, it is better to have balanced panel data, but unbalanced ones entail some computational and estimation issues although most software packages in recent times are capable to handle both balanced and unbalanced panels (Cameron and Trivedi, 2009). Rachid *et al.* (2006) estimated import demand of countries based on unbalanced panel data models. Eriket *et al.* (2006) used unbalanced panel data over the period 1972 to 1993 and identified negative trend in the number of firms participated in different industries. Gravelle *et al.* (2002) also used an unbalanced panel data set for 191 countries as a sample and analyzed these data using the fixed effects model.

3.4. Methods of Data Analysis

The research had different objectives that demand generation of different dependent variables and employment of appropriate data analysis methods. This indicates that method of analysis is mainly depending on the predefined objectives and nature of the dependent variable as well. Some objectives require simple descriptive method of analysis like tabulation, graphical representation and other simple mathematical statistics (mean, median, mode and ratios) especially in qualitative data based research works. Objectives addressed through quantitative

data may require employment of mathematical models and/or econometric tools. Thus, the four main objectives of this research entailed the following method of data analysis.

3.4.1. Effect of Climate Variability on Crop Yield

This study considered the five major cereal crops namely *teff*, wheat, maize, barley and sorghum to examine the effect of climate variability on yield. Nastis *et al.* (2012) considered production per unit of land as a dependent variable to analyze the impact of climatic variability on agricultural productivity in Greek. Similarly, yield of the cereal crops was used as a dependent variable in this research. The mathematical formulation was based on Cobb-Douglas production function, which assumes that agricultural production is a function of inputs like cultivated area, oxen power, fertilizers, labors, capital, rainfall and temperature. The study tested compatibility of trans-log function, but it was not companionable in the regression process considering the square and interaction terms of covariates.

Functional form of the model was:

$$TP_{iht} = F\{AS_{iht}, IFA_{iht}, AL_{iht}, WC_{iht}, DP_{iht}, R_{irt}, T_{irt}\} \quad (14)$$

Where: $i=1,2,\dots,5$ (for the five cereals)

$h=1,2,\dots,H$ (the sample household)

$t=1,2,\dots,8$ (the eight round sample years)

TP_{iht} = Total Production of sample cereal i for smallholder h at year t

AS_{iht} = crop-wise Area Sown by each smallholder h at year t

IFA_{iht} = Inorganic Fertilizer Application for each crop by smallholder h at year t

AL_{iht} = Agricultural Labor of each smallholder h for each crop at year t

DP_{iht} = Draught Power of each smallholder h for each crop at year t

WC_{iht} = the Working Capital budgeted by smallholder h for each crop at year t

R_{irt} = Cropping season rainfall level for each crop i from the nearest meteorological site r at time t

T_{irt} = Average cropping season temperature for crop i from the nearest meteorological site r at time t

Thus, total production (TP) should be divided by area sown (AS) of each sample cereal i to get yield, then the above equation would become:

$$(TP/AS)_{iht} = Q_{iht} = F\{IFA_{iht}, AL_{iht}, WC_{iht}, DP_{iht}, R_{irt}, T_{irt}\} \quad (15)$$

$(TP/AS)_{iht} = Q_{iht}$ is yield of sample cereal i for smallholder h at t production year. After computing yield of each cereal, then the above equation would take the following form:

$$Q_{iht} = F\{IFA_{iht}, AL_{iht}, WC_{iht}, DP_{iht}, R_{irt}, T_{irt}\} \quad (16)$$

Thus, equation 16 can be rewritten following Battese and Coelli, (1992):

$$\ln Q_{iht} = \ln [f(X_{it}, \beta) \exp(V_{it} - U_{it})] \quad (17)$$

And

$$U_{it} = \eta_{it} U_i = \{\exp(-\eta[(t-T_i)])\} U_i \quad (18)$$

Q_{iht} represents yield of cereal i for the i^{th} household at the t^{th} period; $f(X_{it}, \beta)$ is a suitable function of a vector, X_{it} , of factor inputs associated with production of i^{th} cereal in the t^{th} period, and a vector, β , of unknown parameters. The random effect, U_i is independent and identically distributed (iid) non-negative truncations with $N(0, \sigma_\mu^2)$, V_{it} is also iid $N(0, \sigma_v^2)$ random errors and independent of μ_i . η is an unknown scalar parameter that shows the type of yield variation. Household's technical efficiency (TE) tends to improve, remain constant if not decrease in producing cereals towards the base year, 2014 if $\eta > 0$, $\eta = 0$ or $\eta < 0$, respectively. The time period $t = 1, 2, \dots, T_i$ periods for which observations for the i^{th} household are obtained.

From equation 17 and 18 TE of household h for producing the i^{th} cereal at time t would be:

$$TE_{iht} = \frac{Q_{iht}}{Q_{iht}^*} = \frac{f(X_{it}, \beta) \exp(V_{it} - U_{it})}{f(X_{it}, \beta) \exp(V_{it})} = \exp(-U_{it}) \quad (19)$$

To deal with factors affecting smallholder's efficiencies in cereal production, different socio-economic and climate variability elements were considered on the regression using Generalized Least Squares (GLS). This model was employed because the TE scores of all the observations were between 0 and 1, but not 0 or 1, which allowed to have linear type of dependent variable. Since the dependent variable was based on panel data, the appropriate

regression model was GLS that consider heteroscedasticity and panel-autocorrelation problems. The functional form of the efficiency equation could be:

$$TE_{iht} = \sum \alpha_i X_{ht} + v_i + \varepsilon_{it} \quad (20)$$

Where: TE_{iht} = the TE scores of smallholder h for cereal i at time t

α_i = a vector of unknown parameters ought to be estimated

X_{ht} = a vector of explanatory variables i ($i = 1, 2, \dots, k$) for household h

v_i = an error term that is iid, $N(0, \sigma_v^2)$, and it is the time invariant part of error term

ε_{it} = the time variant error term that should be iid, $N(0, \sigma_\varepsilon^2)$ independently of v_i

The dependent variable for the stochastic frontier model

Deschenes and Greenstone (2006) adopted production per acre planted of soybeans and wheat as the dependent variable. Similarly, Elodie (2012) considered yield of crops as a dependent variable to examine effect of climate change in SSA. Anthony *et al.* (2011) used similar dependent variable. Yield of each sample cereal crop for each smallholder, measured as the ratio of quantity produced to cropland sown; was the dependent variable in the first objective of this research, and the frontier regression considered the following explanatory variables.

Human labor: It is one important factor in agricultural production system that demands large labor participation especially in the peak periods. Man equivalent of each household was considered for each cereal production. Quality of labor inputs contributed more to increase *teff* yield and in larger farms quality of the input had a much more significant role in yield variations (FAO, 2009a). The same logic may hold true for smallholders in the two farming systems and the covariate would affect the dependent variable positively.

Draught power: It is a critical input for Ethiopian smallholders, who manage their crop production by traditional oxen-plow wooden materials. Availability of oxen (draught) power to smallholders is highly determining factor in the crop production system. Pair of oxen available to each household could be the unit of measurement and it would have positive effect on increasing crop yield.

Inorganic fertilizer: Fertilizer applications raised maize yields, since the use of fertilizer was low on the smallholder farms, fertilizer applications did not have much effect on yields (FAO, 2009b). Integrated application of organic and inorganic fertilizer could increase crop yield (Habtamu *et al.*, 2015). This study considers application of DAP and/or Urea measured in kilogram and expected to have positive effect on yield of the sample cereals.

Working capital: Production inputs like pesticides, the local seeds, insecticides, additional labor employment and other inputs could enhance crop yield. The actual amount of money spent for purchasing those inputs considered as one covariate and expected to have positive effect on yield of each cereal crop.

Rainfall: Dell *et al.* (2008) used annual variations in temperature and precipitation for the previous half century to study impacts of climate change on the world economy. Edeme *et al.* (2011) considered annual deviations of precipitation. Govinda (2013) used average cropping season rainfall level to examine effect of climate change on wheat, barley, sorghum and maize production. Based on the premise of plant physiology, seasonal data is more relevant for estimating the effect of climate variability on crop production than the annual level (Mathilde and Kubik, 2014). It is not rational to use cumulative annual rainfall but rather it is better to use growing season rainfall (Zaal *et al.*, 2004). The same crop type, for instance maize, may be different in its variety for some behaviors and characteristics when it grows in different agro-ecologies. The data what this research considered were not long enough to calculate rainfall deviation from the actual level. To calculate the deviation term it is necessary to have long run average for each sample *kebele*, which was impossible due to data inconsistency from the national meteorology. The rainfall variable in this research was constructed over the growing season of each crop in each *kebele* considering actual rainfall level in the season from the nearest meteorology site.

Temperature: Joshi *et al.* (2011) adopted daily mean temperature to assess effects of global warming on grain crop production. Increment of mean temperature in tropical regions, wherein crops are at their optimum level, is likely to have negative effect particularly for

cereal crops (IPCC, 2007b). This implies that temperatures above the optimum level of crop's growth will be damaging and this research expected similar circumstance. Given this, the research considered the nearest meteorology sites as a source of average daily cropping season temperature for each sample cereal in each *kebele* of the two farming systems.

Table 4. Summary of the variables considered as determinants of cereals yield

Explanatory variables	Measurement	Hypothesized effect
Human Labor	Continuous (Man equivalent)	+
Draught power	Continuous (Pair of oxen)	+
Working capital	Continuous (in <i>Birr</i>)	+
Inorganic Fertilizer	Continuous (kilogram)	+
Rainfall	Continuous (mm)	+/-
Temperature	Continuous ($^{\circ}\text{C}$)	+/-

Definition of variables for technical efficiency (TE)

Dependent variable

Stochastic frontier model output of each cereal was the base to generate the dependent variable in the TE regression. TE of household *h* in producing crop *i* was predicted from the stochastic frontier regression result. The hypothesis to be tested was how climate variability elements and other socioeconomic factors affect smallholders' TE in producing cereals. Based on empirical reviews, this study considered three broad categories of explanatory variables including demographic, economic and climate related ones, in the regression.

Explanatory variables

Household size: It is a continuous variable considering the total man equivalent calculated based on the standard conversion rate. Since labor is the main input in the crop production of smallholders, then this variable is expected to affect efficiency level of farmers positively. A smallholder that has large family size could carry out each crop production practices timely. Family size had positive effect on economic efficiency (Rehman and Umar, 2009; Sisay *et al.*, 2015). Some authors including Mekdes (2011) argued that large family size might increase expenditure for consumption, which affect smallholders' efficiency negatively.

through creating financial constraints for the crop production. Thus, final effect of the covariate on TE would be dependent on the magnitude of the two effects.

Household head education level: Education enables farmers to have information access, new ideas, knowledge and skill about efficient utilization of scarce resources. Sisay *et al* (2015) claimed that education level had positive effect on maize production efficiencies. It was continuous variable based on number of years at school. Positive effect is expected on households' TE in producing cereals.

Age of the household head: Hardwick (2009) argued that the quantity and productivity of household labor is one critical determinant of agricultural efficiency. Since this study focuses on TE of households in producing cereals, younger household head would have the courage and energy to allocate the demanded production labor that could enhance TE. Therefore, it is hypothesized that household's TE in producing cereals would be better if younger heads manage it.

Credit access: This is a dummy variable constructed as 1 if any of the household member has access to credit in each survey year otherwise 0. It affects smallholder's capacity to purchase the necessary agricultural inputs at the right time. FAO (2014) notified that access to credit is one critical determinant of TE for specialized farmers in Chile. Thus, easy access to credit would have positive effect on TE of households to produce cereals.

Off/non-farm activities: It was measured as a dummy variable that took value of 1 if a member of the household participated in off/non-farm activities and 0 otherwise. Kindie (2005) found that off/non-farm activities had positive effect on smallholders' TE. There may be competition between agriculture and participation in those activities for critical inputs like human labor and scarce capital. This circumstance would negatively affect TE of households and hence agricultural activities. It can also affect TE positively by reducing household's financial constraints in purchasing all the necessary farm inputs.

Climate shocks: Developing nations are more vulnerable to the stresses and shocks (flood, drought and frost) brought by climate variability (Corinne *et al.*, 2004). Unexpected climate

variability has negative effect on wheat and maize yield (IPCC, 2014b). Michel and Christopher (2013) indicated that unexpected short-run factors or natural disasters because of climate variability would result in drastic crop yield reduction. For each crop, there is temperature level at which crops grow best across the seasons, and going above or below that level would have negative effect (Julie and Corene, 2014). Cereal yields can be damaged by a few days of temperatures above or below a certain threshold level (Wheeler *et al.*, 2000). Mathilde and Zaneta (2014) similarly argued that temperature shock would significantly reduce crop production. The circumstance would be the same for cereal crops considered by this research in the two farming systems. The covariate was dummy type taking value of 1 if a household suffered from one of the problems (flood, drought and frost) and 0 otherwise.

Summer rainfall onset: It was one dimension to measure rainfall inconsistencies of the study area for each sample household. It was a dummy variable taking 1 if there was happening of the problem for each household and 0 otherwise.

Harvesting season rainfall: Untimely rainfall at harvesting season of each crop may reduce efficiency of smallholder in producing cereals. It was a dummy variable taking 1 if there was happening of the problem for each individual household and 0 otherwise.

Pests and disease outbreak: This variable is directly related with cropping season rainfall and temperature variability for each household. Dinesh *et al.* (2015) argued that climate variability might bring risk of pests and diseases outbreak to African agricultural systems, affecting crop productivity. It would be dummy variable taking value 0 if there is no outbreak or else 1 if there was an outbreak within the cropping season for each household.

Table 5. Description of variables that affect technical efficiency

Variable description	Units of Measurement	Hypothesized effect
Household size	Man equivalent	+/-
Household head education	Dummy literate=1, otherwise=0	+
Livestock holding	TLU	+
Age of the household head	Years	+
Credit access	Dummy Yes=1, otherwise=0	+
Off/non-farm activities	Dummy Yes=1, otherwise =0	+/-
Climate shocks	Dummy Yes=1, otherwise =0	-
Summer rainfall onset	Dummy Yes=1, otherwise =0	+

Harvesting season rainfall	Dummy Yes=1,otherwise =0	-
Pests and disease outbreak	Dummy Yes=1,otherwise =0	-

3.4.2. Effects of Climate Variability on Crop Income

The Ricardian approach argued that environmental factors affect production and costs, and result in generating new net revenue for each household. It assumed that climate changes are instantaneous and the economy could adjust to these changes completely, so that land prices reflect a long-run climatic equilibrium. Thus, each smallholder wishes to maximize income subject to exogenous conditions of the farm. Smallholders could select the crop inputs for each unit of land that maximizes income (Mendelsohn *et al.*, 1994). DiFalco (2011) employed Ricardian analysis and used net revenues as a dependent variable. This can be particularly useful if yields of different crops aggregated to generate income. John (2009) argued that gross value of production or net farm income might be used to examine farm-level impact of climate variability on rural households' crop income. Nhemachena *et al.* (2010) considered net farm revenues to measure economic impact of climate change on African agricultural production systems. This research followed similar logic and considered gross margin collected from crop, measured in terms of *Birr*, as a dependent variable. Thus, this research formulated smallholder's crop income in the two farming systems as a function of price and quantity sold:

$$Y_{hrt} = F[P_{irt} Q_{iht}] - \sum I_{it} X_{it} \quad (21)$$

Where: Y_{hrt} = Crop income of a smallholder (h) in a specific *kebele* (r) at year t,

P_{irt} = Market price of crop i in each *kebele* r at year t. The research assumed that rural smallholders in each *kebele* have one common market wherein crop price could be equal for sample households within a *kebele*.

Q_{iht} = Quantities of crop i sold by smallholder h at year t

X_{iht} = is a vector of production inputs such as labor, fertilizer, seeds, and pesticides used by smallholder h for crop i at production year t

I_{it} = quantity of each input budgeted in the production. The summation of the product of quantity and unit price could result in generating total cost of production.

The above functional form implies that smallholder's crop income is a function of crop price charged and quantity sold. Apparently, crop prices largely influenced by the local supply and

demand forces (Liqiang, 2005). The author argued that total value of corn and bean strongly correlated to the yield. Quantity of crop sold could be a function of both production inputs and other factors like socioeconomic, demographic, and climate related ones.

$$Y_{hrt} = \sum P_{irt} Q_{iht} (K_{iht}, L_{iht}, F_{iht}, C_{iht}, H_{iht}, S_{iht}, O_{iht}) - \sum I_{it} X_{it} \quad (22)$$

Where: K_{iht} = capital budgeted for the crop production i by household h at year t

L_{iht} = is human labor budgeted for the crop production by household h at year t

F_{iht} = Inorganic fertilizer used for crop i by smallholder h at year t

H_{iht} = Demographic characters at year t that affect quantity of crops available for sale

C_{iht} = Climate variability elements that affect quantity of crop available for sale by household h at survey year t .

S_{iht} = Represent socioeconomic factors that affect the quantity of crops available for sale by household h at survey year t .

O_{iht} = Other covariates like off/non-farm activities that affect quantity of crops available for sale by each household at year t

Panayotis and Alexander (2007) assumed that produce prices are independent of quantity produced by the household. Since the crop market in Ethiopia is a perfect competitive type with many sellers and buyers, an individual smallholder has not the power to determine crop price. Thus, smallholders in the sample farming systems could be price takers that exchange based on the existing market price level. This implies that the main actor in changing smallholder's crop income would be variation in quantity of crops available for sale. Income of small-scale farmers' in developing countries would decline sharply if their crop production fails since the sub-sector is the main source of income (Thomsen and Metz, 1998). Jehovaness (2010) considered climate related variables like rainfall, temperature and flood as exogenous variables, and regressed separately, which was not logical due to data mining or regression fishing problem. Smallholders in Ethiopia mostly made production decisions several months in advance of actual sale. Based on the above equation, the quantity of crops available for sale could be a function of production inputs, household related variables and climate related factors.

$$Q_{iht} = F(K_{iht}, L_{iht}, H_{iht}, F_{iht}, C_{iht}, S_{iht}, O_{iht}) \quad (23)$$

Equation 23 implies that some of the climate variability elements have a direct brunt on quantity of crops available for sale and consequently have an induced effect on smallholders' crop income. Variability in temperature and rainfall intensity is likely to affect crop productions and the ultimate effect would be on smallholders' revenue (IPCC, 2001). If a farmer chooses the crop that provides the highest net income and select each input (*i.e.* quantity produced) in order to maximize net income, the resulting equation would be a function of just the exogenous variables only (Mendelsohn *et al.*, 1994) due to having the reduced form of the original function. Then, the above function would be:

$$Y_{hrt} = (P_{irt}, K_{iht}, L_{iht}, H_{iht}, F_{iht}, C_{iht}, S_{iht}, O_{iht}, I_{iht}) \quad (24)$$

Each change in smallholder's income sourced from variation in one of those variables or simultaneous change in two or more of them at a time. Additionally, available inputs in connection to marketing and other demographic shocks may affect households' crop income through changing quantity of crops available for sale, thus equation 24 can be rewritten as:

$$Y_{hrt} = (P_{irt}, K_{iht}, L_{iht}, H_{iht}, F_{iht}, C_{iht}, S_{iht}, O_{iht}, I_{iht}, D_{hrt}) \quad (25)$$

D_{hrt} = Demographic related shocks for household h at a specific time t in each *kebele* r . To simplify regression of the above equation crop revenue approximated the dependent variable, net crop income. Temesgen (2006) considered net farm revenue to assess economic impact of climate change. Jain (2006) also adopted the same variable to assess impacts of climate change on Zambian agriculture. In the same fashion, this research approximated smallholders' net crop income by revenue collected from crop production only. Thus, the above equation reformulated as:

$$\ln Y_{hrt} = \theta_1 \ln P_{irt} + \theta_2 \ln K_{iht} + \theta_3 \ln L_{iht} + \theta_4 \ln H_{iht} + \theta_5 \ln F_{iht} + \theta_6 \ln C_{iht} + \theta_7 \ln S_{iht} + \theta_8 \ln O_{iht} + \theta_9 \ln I_{iht} + \theta_{10} \ln D_{hrt} + \alpha_i + \varepsilon_{it} \quad (26)$$

Where the individual-specific effects $\alpha_1, \dots, \alpha_N$ measure unobserved heterogeneity that is possibly correlated with the other regressors, X_{it} (Cameron and Trivedi, 2005). Cropping season rainfall and temperature variation considered as an approximate to climate variability (C_{iht}), which might take the right hand share in affecting the dependent variable, crop income. Extreme

climate variability sourced shocks such as droughts, flooding and frost severely affect the quantity of crop available for sale by smallholders. Thus, there would be inclusion of shocks and other rainfall inconsistencies as an explanatory variable. Considering all these, the above equation transformed into the following form:

$$\ln Y_{hrt} = \theta_1 \ln P_{irt} + \theta_2 \ln K_{iht} + \theta_3 \ln L_{iht} + \theta_4 \ln H_{iht} + \theta_5 \ln F_{iht} + \theta_6 \ln R_{rt} + \theta_7 \ln T_{rt}^0 + \theta_8 \ln I_{iht} + \theta_9 \ln RI_{ht} + \theta_{10} S_{iht} + \theta_{11} O_{iht} + \theta_{12} \ln D_{hrt} + \alpha_i + \varepsilon_{it} \quad (27)$$

R_{rt} and T_{rt}^0 denote cropping season rainfall and temperature level in each villager at year t

RI_{ht} refers rainfall inconsistencies and shocks sourced from climate variability, which is different for each household h at year t .

Explanatory variables

Temesgen (2007) considered household related variables like livestock ownership, education level of the head, distance to input markets, household size, linear and quadratic temperature and precipitation terms for the four seasons and other control parameters as explanatory variables in analyzing economic impact of climate change on Ethiopian agriculture. Ajay and Pritee (2013) considered agricultural labor, rainfall, temperature and others as independent variables in analyzing impact of climate variation on agricultural production. Given all the above, this research considered the following variables as an explanatory.

Family size: Attaining higher net farm revenues strongly depends on factor endowments (i.e. family size, cropland and capital) at the disposal of farming households (Nhemachena, 2010). It is critical input expressed in terms of man equivalent for each household at time t . This variable has two contradictory effects on crop income, which are the consumption effect that reduce crop income and production effect that increases it. Thus, direction of the final effect of human labor on crop income would be dependent on the magnitude of the two effects.

Rainfall: Julie and Corene (2014) showed that in a period where monthly rainfall seldom occurred in normal amounts, most households experienced agricultural income reduction. Household's net agricultural income may be negatively affected by a decline in rainfall, especially in rain-fed agriculture (James *et al.*, 2009). In this research, the rainfall variable was

constructed based on actual cropping season amount (measured in mm) over the crop-growing season collected from the nearest meteorological site to each sample *kebele*.

Temperature: Michelle (2003) used monthly climatic normal deviations to examine climate variability. Agronomists have shown that plant growth depends on the cumulative exposure to heat and precipitation during the growing season (Grierson, 2002). The number of years having well-organized temperature data are very few for each meteorology site to consider deviation of each month from the long-term crop season average. This research considered average cropping season temperature collected from the nearest meteorological sites to each sample *kebele*. The serious multicollinearity problem prohibit consideration of the quadratic temperature as an explanatory variable in this research.

Interaction of rainfall and temperature: Interaction of the two dominant climate related variables (cropping season rainfall and temperature) would result in smallholders' crop income improvement in the two farming systems due to counterbalancing negative effect of the one with positive effect of the other. This positive effect of the variable is due to counterbalancing negative effect of the one with positive effect of the other. This logic could hold true if there is successive increment in both cropping season rainfall and temperature.

Climate related shocks: This variable encompasses different shocks like flood, drought and frost. Flood may reduce overall crop income of households through reducing the quantity of crop available for sale. Impacts from recent climate-related extremes, such as heat waves, droughts and floods reveal significant vulnerability on many human beings because of the recurrent climate variability (IPCC, 2014b). Temperature rise would have negative effects on farm net revenue (Edeme, 2010), which implies that drought would reduce smallholders' crop income.

Diseases and pest infestation: Dinesh *et al.* (2015) argued that climate change would bring greater risk of pests and diseases to African agricultural systems, affecting crop, livestock, and fisheries productivity. The authors found that areas affected by both wet and dry rainfall extremes could decrease well-being of rural households. Countries characterized by highly variable rainfall and exposure to extreme events, particularly if coupled with high levels of poverty, result in drastic income reduction (Julie and Corene, 2014). It would be dummy type

taking 0 if there is no outbreak or 1 if there is within the cropping season in each smallholder, and would affect crop income through reducing quantity of crop available for sale.

Saving: Availability of working capital and diversified income source could be possible if the household has saving in the formal or informal institutions like *equb* or *edir*. It was dummy variable based on household members participation to either of the two institutions, and would have positive effect on the dependent variable.

Cropland size: Larger farm sizes appear to have positive effect on net farm revenue across all farm types, suggesting that more cropland allows smallholders to diversify their crop production, leading to better income (Nhemachena *et al*, 2010). Larger cropland possession, measured in hectare, would result in having positive effect on gross income via increasing the quantity of crops available for sale.

Off- and/or non-farm activities: They are alternative source of income for rural households, which would reduce uncertainties due to having one source of income. Thus, if the household has access to participate either in off- or non-farm activities, then there would be reduction in crop income due to labor competition. Given this, those activities may be one source of working capital for the well performance of the crop production that would increase income.

Number of oxen: Draught power is critical input in the crop production of smallholders in Ethiopia. Possessing large number of oxen would increase the potential of having higher draught power that would increase efficiency in crop production and better opportunity of collecting higher crop income.

Livestock holding (TLU): Possession of large livestock unit (excluding oxen) may have two directional effects on smallholders' crop income in the two farming systems. It may increase crop income because of being additional source of capital and power for the crop production. In the other direction, households may face labor and working capital competition for the two sub-sectors of agriculture, which would reduce marketable quantity of crops.

Rainfall inconsistency: It includes rainfall at harvest, enough rain at beginning and summer rainfall on time availability. Late start or early cessation of the crop season as well as harvesting time rainfall may affect the crop production that could reduce the marketable quantity of crops for smallholders in the two farming systems.

Idiosyncratic shock: Francis and Tomoya (2013) showed that areas with conflicts have 17% lower yield than those free of the problem, which means it hurts productivity seriously. It is a dummy variable taking value of 1 if one of the problems occurrence or else 0, and the research proposed that it would have negative effect on households' crop income in the two farming system.

Table 6. Summary of explanatory variables for crop income

Explanatory variables	Description	Hypothesized effect
Rainfall	Continuous (mm)	-
Temperature	Continuous ($^{\circ}\text{C}$)	-
Rainfall X Temperature	Continuous (numeric)	+
Rainfall at harvest	Dummy (1 if there was, 0 otherwise)	-
Enough rain at beginning	Dummy (1 if there was, 0 otherwise)	+
Summer rain on time	Dummy (1 if there was, 0 otherwise)	+
Number of oxen	Continuous (Numeric)	+
Livestock size	Continuous (Numeric)	+/-
Idiosyncratic shock	Dummy (1 if there was, 0 otherwise)	-
Off/non-farm activities	Dummy (1 if there was participation, 0 otherwise)	-/+
Crop residue	Dummy (1 if there was collecting and selling, 0 otherwise)	+
Climate sourced shocks	Dummy (1 if there was, 0 otherwise)	-
Disease and pest outbreak	Dummy (1 if there was, 0 otherwise)	-
Access to credit	Dummy (1 if there is access, 0 otherwise)	+
Cropland	Continuous (hectare)	+
Family size	Continuous (numeric)	+/-

3.4.3. Adaptation Options to Climate Variability

Since they have not resources to invest for improving their adaptive capacity developing countries in the Tropics are worse off than developed ones under different scenarios of climate change (Corinne *et al.*, 2004). Households in developing nations adopt different strategies like soil conservation schemes, changing crop variety, planting trees, water harvesting, sought off-farm activities, planting late or early, migration to urban areas or adopting new technologies in order to reduce the negative brunt of climate variability (Nhemachena and Hassan, 2007). Those are common adaptation methods for smallholders in low-income countries. Households of the rural economy are having different mechanisms in order to adapt climate variability (Arjan *et al.*, 2011). Pytrik *et al.* (2015) considered only changing the sowing date and the crop varieties in simulated adaptation measures. Households always try to implement different adaptive mechanisms though they may not be free from effect of climate variability.

Kurukulasuriya and Mendelsohn (2006), and Seo and Mendelsohn (2006) employed multinomial logit model for analyzing determinants of adaptation choices to curve the negative effects of climate change. Temesgen (2010) also used multinomial logit to identify determinants of six alternative adaptation options employed by smallholders assuming that the alternatives are mutually exclusive, which may not be logical assumption since smallholders are rational enough to utilize two or more of the methods in one crop season. Adaptation measures that smallholders employ may be profit driven or cost effective type, rather than climate change driven as to the work of the above author. However, this study assumed that households' ability to implement and collect benefits from each strategy were the bases for categorizing adaptation strategies. Hence, smallholders in the two farming systems had four alternative adaptation strategies.

- ❖ **Changing sowing time (Strategy_1):** includes changing the sowing time like planting early or late, early harvesting and other activities.

- ❖ **Technology adoption (Strategy_2):** comprises adoption of agricultural technologies including new crop varieties, pesticide, insecticides and other new technologies.
- ❖ **Alternative income sources (Strategy_3):** includes searching alternative income sources such as temporal migration, off- and non-farm income, petty trade and artistic works.
- ❖ **Conservations (Strategy_4):** encompasses adopting other strategies like reforestation, water harvesting, irrigation, erosion prevention *etc.*

The four alternative strategies could be grouped into two (short-run and long lasting) sub-unites based on the time needed to collect benefits. Reilly and Schimmelpfennig (1999) argued that adoption of tillage systems, variety and fertilizer needs shorter period of not more than 10 years, but strategies like dams and irrigation development, and afforestation need more longer years of about 20 years. Thus, the research grouped the first and third strategies as short run, and the second and fourth strategies as long lasting type. Smallholders implement the first and third strategies as short run remedy to cure immediate problems, and they adopt the second and fourth strategies as long lasting measures for combating climate variability.

There are different problems behind the potential and willingness of smallholders to adopt those mechanisms. The study used the eighth round data collected in 2014 to assess determinants of smallholders' adaptation strategies. They may adopt one or more of the four alternatives, which would result in having mutually inclusive choices and correlated error terms (Cameron and Trivedi, 2005). The multiple-equation model or multivariate probit (MVP) model, with four dependent variables is given by:

$$\left\{ \begin{array}{l} Y_1 = X_1\beta_1 + \varepsilon_1, y_1 = 1 \text{ if } Y_1 > 0, 0 \text{ otherwise} \\ Y_2 = X_2\beta_2 + \varepsilon_2, y_2 = 1 \text{ if } Y_2 > 0, 0 \text{ otherwise} \\ Y_3 = X_3\beta_3 + \varepsilon_3, y_3 = 1 \text{ if } Y_3 > 0, 0 \text{ otherwise} \\ Y_4 = X_4\beta_4 + \varepsilon_4, y_4 = 1 \text{ if } Y_4 > 0, 0 \text{ otherwise} \end{array} \right\} \quad (28)$$

And

$$\left\{ \begin{array}{l} E\{\varepsilon_1|X_1, \dots, X_4\} = E\{\varepsilon_2|X_1, \dots, X_4\} = \dots \{\varepsilon_4|X_1, \dots, X_4\} = 0 \\ Var\{\varepsilon_1|X_1, \dots, X_4\} = \{\varepsilon_2|X_1, \dots, X_4\} = \dots \{\varepsilon_4|X_1, \dots, X_4\} = 1 \\ Cov\{\varepsilon_1, \varepsilon_2|X_1, X_2\} = \rho_1, Cov\{\varepsilon_1, \varepsilon_3|X_1, X_3\} = \rho_2, Cov\{\varepsilon_1, \varepsilon_4|X_1, X_4\} = \rho_3 \\ Cov\{\varepsilon_2, \varepsilon_3|X_2, X_3\} = \theta_1, Cov\{\varepsilon_2, \varepsilon_4|X_2, X_4\} = \theta_2 \\ Cov\{\varepsilon_3, \varepsilon_4|X_3, X_4\} = \gamma \end{array} \right\} \quad (29)$$

Where the X_i s are vector of explanatory variablesthat determine adaptation of the four alternative strategies available for each smallholder, in which $i = 1, 2, 3$ and 4 for each equation Y_1, Y_2, Y_3 and Y_4 , respectively.

Explanatory variables for determinants of adaptation

Household income level: Coping capacities could improve when households have more income earning opportunities (Arjan *et al.*, 2011) and result in having better potential of adopting different methods. Income sourced from different activities like crop production or livestock management, non- and off-farm, remittance, aid and other sources may increase smallholder's capacity to adopt climate variability. This variable expressed in terms of money and expected that it would have positive effect on smallholders' adaptation behavior. Reverse causality between current income and previous year adaptation could not be there since the data for this objective are cross sectional type.

Human labor: Changes in input factors such as financial and physical resources, infrastructure, knowledge and human resources may change adaptation capacity of households over time (Ringler, 2010). Farm assets (labor, land and capital) are critical for helping African farmers to adapt climate change (Hassan and Nhemachena, 2008). Human resources or social characteristics (Jones and Boyd, 2011) of households affect access to information and in turn, it will highly affect adoption behavior of them. The study considered man equivalent of each smallholderand expected to have positive interaction with the dependent variables.

Access to credit: It implies availability of different source of finance from either legal or illegal lenders. Financial constraints and difficulty to obtain affordable loans by smallholders are most commonly observed constraints for all strategies. There is very high confidence thatlack of financial resources (in the form of credit) isone major bottleneck in the adaptation behavior of farmers in Africa and Asia (Temesgenet *al.*, 2009). Adaptation strategies will not

be successful unless financial constraints are not solved (Arjanet *al.*, 2011). This dummy variable based on access would have positive effect on smallholder's adaptation behavior.

Rainfall inconsistency: It includes previous cropping season year rainfall shortage and rain at harvesting season. Consistent availability of crop season rainfall would determine sustainable production of crops. Gbetibouo *et al.*, (2010) suggested that access to water and extension services are key inputs to enhance farmers' adaptive capacity. The same logic may hold true in this research where cropping season rainfall inconsistency at onset, growing period, cessation and harvesting season could be considered in dummy variable format.

Access to market: Currently, low quality infrastructure, poorly functioning markets, and low purchasing power (Arjan *et al.*, 2011) may hamper adaptation initiatives. For rural households' lack of access to markets is a major barrier in adopting agricultural production strategies. Households adopted improved technologies; especially improved maize seeds combined with better market access had significantly higher income (Cunguara and Darnhofer, 2011). The variable approximated by the distance between all-weather road and dwelling place of each farm household. Thus, distant located smallholders would restrain to adopt strategies that need strong market interaction.

Climate sourced shocks: It includes drought, flood and frost that may be different for each household. It is one of the most common climate sourced shocks faced by farm households and majority of them perceived it as a major threat than flood hazards or storms (Arjanet *al.*, 2011). Occurrence of frequent flood may initiate farm households to adopt new technologies that reduce its impact. Smallholders could be active enough in looking for alternative strategies if there is frequent flood, drought or frost. This dummy covariate would have positive effect on the probability of adopting one of the alternative strategies.

Diseases and pest: Earlier studies identified that climate variability especially inconsistencies in cropping season rainfall frequently result in outbreak of crop disease and pests, which would have strong negative effect on productivity. This circumstance could directly affect the crop yield and income. Frequent outbreak of the problem may initiate farm households to look

for adaptation strategies to cope up with the problem. It could be constructed as dummy variable taking 1 if there was outbreak of the problem and 0 otherwise.

Infrastructural facilities: Hassan and Nhemachena (2008) showed that better access to technologies is critical for helping African farmers to adapt the changing climate. Infrastructural facilities include access to electrification and pipe water may enhance crop production and marketing system that would increase awareness of smallholders to identify the appropriate strategy clearly. Having access to those facilities could improve their adaptation capacity.

Food self-sufficiency: If a household fully satisfied its food requirement, then the effort would be on producing more and generating additional buffer income. This circumstance indicated that if a household were food self-sufficient its capacity to adopt different strategies would be high.

Crop price: Price increases would likely have significant effect on farm income and enhance adaptation capacity of farmers to curve negative effect of climate changes (Pytrik *et al.*, 2015). It is a continuous variable measured in Ethiopian Birr and affect probability of alternative adaptation strategies.

Table 7. Summary of explanatory variables for household's adaptation behavior

Explanatory variables	Description	Hypothesized effect
Total income	Continuous (in Birr)	+
Rainfall shortage	Dummy (1 if there was, 0 otherwise)	-
Harvest season rainfall	Dummy (1 if there was, 0 otherwise)	-
Human labor	Continuous (man equivalent)	+
Access to electric	Dummy (1 if there is access, 0 otherwise)	+
Access to pipe water	Dummy (1 if there is access, 0 otherwise)	
Climate related shocks	Dummy (1 if there was, 0 otherwise)	+
Disease and pests	Dummy (1 if there were, 0 otherwise)	-
Distance from the road	Continuous (km)	+
Food self sufficiency	Dummy (1 if there was, 0 other wise)	-
Crop price stability	Inflation index	+
Saving account	Dummy (1 if there was participation, 0 otherwise)	+

Expected drought	Dummy (1 if the household expected it, 0 otherwise)	+
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3.4.4. Effect of Climate Variability on Rural Labor Displacement

Mathilde and Zaneta (2014) proposed that climate variability has induced effect on farm household member mobility through its direct effect on agricultural yields. Temperature or precipitation shock decreases yield and as a consequence household's income, which in turn induces the family to send its member away. This indicated that climate variability does not affect migration decision directly, but it may affect through its amenity value or through household's preferences for a given climatic setting. Thus, climate variability elements could not appear directly in the migration equation. Michel and Christopher (2013) found indirect relationship between climatic change and international migration. Paul *et al.* (2012) considered total annual household expenditures per capita as a determinant of migration.

Some scholars had very strong assumption that climatic factors influence migration indirectly through crop production, but not directly. Kavi and Brinda (2012) considered rice and wheat yield separately as the relevant agricultural variables that determined migration. They used the fraction of out migrants defined as ratio of total rural out-migrants from a state to the rural population of the origin state, as dependent variable. Few studies assumed that rural labor migration is associated with food insecurity and some others connect it with crop yield reduction. It is easy to generalize that rural labor movement mainly sourced from crop income variability in one or the other direction. Since the crops considered in this study were the dominant cereals but not the whole, it would not be logical to consider yield variability as a main source of labor movement. It is generally accepted fact that crop production is the main source of food and income for Ethiopian farm households, and variability in this sub-sector would result in enormous income variation. Thus, it is more logical to say that each crop yield change might result in income variation that would initiate family members to migrate.

$$\left\{ \begin{array}{l} M_{it} = F(Y_{it}) + \varepsilon_{it} \\ \text{and} \\ Y_{it} = F(C_{it}) + \gamma_{it} \end{array} \right\} \quad (30)$$

Where: M_{it} is the number of emigrant from farmhousehold i at year t . Mathilde and Kubik (2014) used a dummy dependent variable for a household having at least one migrant in working age and the preferred temperature and precipitation shock in 2008 one year prior to migration as main climatic variable in the regression. Michel and Christopher (2013) considered the ratio of migrants from the total population of the country in addressing impact of climate change on international migration. The ratio of labor migrated from each household to the total family size in each survey year was the dependent variable in this research. Hence, the ratio could enable this research to generate continuous and normally distributed dependent variable. This conversion could allow the research to have continuously varying type of dependent variable, but not counting data type. In this circumstance, households that have large number of displaced labors could have different value than those with lower number of migrants in each survey year.

Y_{it} = the crop income collected by each farm household i at year t . Since the main objective of this research is to examine interaction of rural labor displacement and climate variability the study considered smallholder's crop income collected from crop production only that is a sector highly susceptible to each climate variation.

C_{it} = represents climate variability elements (rainfall, temperature and other shocks) for smallholder i at period t , and

ε_{it} and γ_{it} represent the error terms.

The crucial assumption made by Harris and Todaro (1973) for modeling rural-urban migration is that the circumstance will continue so long as the expected urban real income at the margin exceeds agricultural product-i.e., prospective rural migrants behave to maximize the expected utility. This indicates that agricultural income is the base to examine rural labor migration. Here the climate variability would affect the crop income directly and the rural-labor displacement indirectly, which implies that consideration of smallholder's crop income as an independent variable that directly affect labor migration is logical enough. Thus, the mathematical formulation seem:

$$\left\{ \begin{array}{l} LM_{it} = \beta_0 + \beta_1 Y_{it} + \beta_2 \theta_{it} + \beta_3 PA_i + \varepsilon_{it} \\ \text{and} \\ Y_{it} = \alpha_0 + \alpha_1 C_{it} + \alpha_2 \Phi_{it} + \alpha_3 Q_i + v_{it} \end{array} \right\} (31)$$

Where:- PA_i = represent vector of variables like socioeconomic, demographic, and other household level dummy ones, which affect the labor displacement directly.

θ_{it} = encompasses additional variables that have direct effect on labor displacement

C_{it} = refers climate variability elements like cropping season rainfall, temperature, shocks and others that affect crop income directly.

Q_i = vector of covariates like demographic types that affect crop income directly.

Φ_{it} = represents other variables that affectsmallholders' crop income.

Simultaneous equation model could illustrate causal interpretation of parameters through having endogenous variables (Cameron and Trivedi, 2005). It is useful to see, in a simple model, that an explanatory variable that is determined simultaneously with the dependent one may generally correlated with the error term, which leads to biasness and inconsistency in OLS regression. Although reduced form models are very useful for some purposes, knowledge of structural or causal parameters is essential for policy analyses. Identification of structural parameters within the simultaneous equations framework poses numerous conceptual and practical difficulties (Cameron, and Trivedi, 2005). It is possible to consider the two-equations; the structural and reduced form that is a single equation managed by pooled OLS, afterexpressing the dependent variable in terms of exogenous co-factors and error terms only (Wooldridge, 2005).

$$LM_{it} = \beta_0 + \beta_1(\alpha_0 + \alpha_1 C_{it} + \alpha_2 \Phi_{it} + \alpha_3 Q_i + v_{it}) + \beta_2 \theta_{it} + \beta_3 PA_i + \varepsilon_{it} \quad (32)$$

Substitution of the second equation to the first one would generate the reduced form;

$$LM_{it} = \beta_0 + \beta_1 \alpha_0 + \beta_1 \alpha_1 C_{it} + \beta_1 \alpha_2 \Phi_{it} + \beta_1 \alpha_3 Q_i + \beta_1 v_{it} + \beta_2 \theta_{it} + \beta_3 PA_i + \varepsilon_{it} \quad (33)$$

Assumptions $Y_0 = \beta_0 + \beta_1 \alpha_0$, $Y_1 = \beta_1 \alpha_1$, $Y_2 = \beta_1 \alpha_2$ and $Y_3 = \beta_3$

$\mu_{it} = \beta_1 v_{it} + \varepsilon_{it}$; it is the within household error across time

$\pi_i = \beta_1 Q_i$ it is the between households error on the same time period

Thus, the final equation would be:

$$LM_{it} = Y_0 + Y_1 C_{it} + Y_2 \Phi_{it} + Y_3 PA_i + Y_4 \theta_{it} + \pi_i + \mu_{it} \quad (34)$$

Explanatory variables to rural labor displacement

Belay (2011) has identified that factors including cropland shortage and others that have connection with the rural economy were push factors for rural-urban migration. Similarly, Kavi and Brinda (2012) considered individual characteristics (sex, age, employment status and economic dependency), household's characteristics (family size, religion and landholding), weather variability (district level average of maximum temperature and annual rainfall) as explanatory variables in studying the implication of weather variability on labor migration. Variability in economic, social, political, demographic and environmental factors and the complex interactions of them remains a major challenge that initiate individuals to migrate (IPCC, 2014a). In the same fashion, this research considered the following explanatory variables to the rural labor displacement from the two farming systems.

Climate related shocks: Climate variability would directly result in different shocks that have strong effect on rural-urban migration (Mertz *et al.*, 2011). Frequent occurrence of these shocks would result in agricultural production reduction and aggravate rural labor migration. Harsh weather conditions will increase the probability of an individual to migrate seeking alternative livelihoods and additional incomes. With the continuous occurrence of a chronic disaster (flood, drought), communities engaged in short-term migration patterns (Clionadh *et al.*, 2009). Occurrence of those shocks valued as 1 and 0 if not, to have dummy variable and the research expected that this variable would aggravate rural labor migration.

Rainfall: Shortage of rainfall significantly increases migration from rural areas across SSA, but not in other parts of the developing world (Barrios *et al.*, 2006). Munshi (2003) found statistically significant and positive correlation between rural migration and rainfall reduction. Similarly, Marchiori *et al.* (2011) claimed that climate variations manifested by variability in rainfall spur both internal and international emigration in SSA. This study considered the actual crop season rainfall from the nearest meteorological site to each sample *kebele* in the two farming systems, wherein households in one *kebele* had similar rainfall level.

Temperature: continuous warming adversely affects crop yields, and then migration increases in the long-term (Fenget *al.*, 2012). Mathilde and Zaneta (2014) identified that climatic variability represented by temperature and precipitation were the main factors for the rural emigration. This study considered average cropping season temperature from the nearest meteorology site to examine effect of temperature variation on rural labor emigration.

Cropland: Having large landholding would reduce the possibility of labor emigration. Regarding economic characteristics of migrants, the general observation is that poor, landless and unskilled individuals dominate the overall migration streams (Montira, 2010). It is measured in terms of hectare and possessing large plot of cropland would reduce labor displacement of farm household members in the study area.

Farm labor: Most migrants tend to come from relatively large families (Montira, 2010). Abundant labor supply within a household might initiate the surplus labor to migrate. Households tend to allocate their labor force optimally over different geographic markets in order to reduce risks if they have surplus labor (Vera *et al.*, 2010). Young adults emigrate in search of a better life due to productivity for long years to generate higher income (DeHaan and Rogally, 2002). This covariate was expressed in terms of man equivalent and would have positive effect on rural labor migration from the two farming systems.

Age of the household head: The youngest age group, those between 15 and 29, are more initiated to have migration decisions if there is a yield shock (Fenget *al.*, 2012). Young people view migration as an avenue to improve their status, learn new skills, and transit into adulthood (Charlotte, 2009). The author argued that youths are an integral component of the migrant population. Consequently, migration continues to serve as a means to improve rural livelihoods in which young household heads would have strong initiation to undertake it.

Household head education level: Less educated people are more likely to be migrants compared to those with middle level education. Studies done before found that educational selectivity existed at both ends of the scale; large proportion among people with very little or no education and among those with high educational levels tended to migrate (Montira, 2010).

The variable measured in the number of schooling years of the head and expected to have negative effect on migration decision of the household.

Livestock holding: The number of livestock units is an important determinant of migration, in which richer households have a higher probability of migration (Mathilde and Kubik, 2014). The reverse may be true in Ethiopia wherein possessing relatively large livestock in terms of TLU implies having better buffer stock and diversified source of income, which would result in lower labor displacement due to climate variability problems.

Capacity to save: It is one way of reducing negative effect of climate variability via having buffered stock for investing in alternative sources of income. Households having access to saving and credit would not need to migrate (Dean, 2003), which may be due to devoting better capacity to cope problems that affect agricultural productivity. In the same fashion, this dummy variable would reduce rural labor displacement from the two farming systems.

Enough rain at the beginning: Since sample of this study were smallholder farmers, their agriculture could be seriously affected by any of the rainfall inconsistencies. Those dummy types of covariates would affect the crop production and income, which finally initiate rural labor displacement.

Summer rainfall onset: It was one dimension to measure rainfall inconsistencies of the study area for each sample household. It was a dummy variable taking 1 if there was happening of the problem for each household and 0 otherwise.

Harvesting season rainfall: Untimely rainfall at harvesting season of each crop may reduce efficiency of smallholder in producing cereals. It was a dummy variable taking 1 if there was happening of the problem for each individual household and 0 otherwise.

Crop residue collection: Participation of the household members in this activity may result in having additional income source to substantiate the main source of income, crop or livestock sales. Generating income from crop residue may provide a diversified source of income for

the household that may enable the family members to have a settled life in their original abode rather than displacing to other areas.

Inflation: Since the sample, smallholders are from areas that produce crops in surplus households are not net buyers rather they are net sellers. Thus, increment in crop price may improve their revenue from crop production. Hence, this circumstance may increase smallholders' income and enable them to prefer settled life in their abode rather than displacing to other areas.

Table 8. Summary of explanatory variables for rural labor displacement

Explanatory variables	Description	Hypothesized effect
Climate related shocks	Dummy (1 if there was, 0 otherwise)	+
Crop income	Continuous (in Birr)	-
Enough rain at the beginning	Dummy (1 if there was, 0 otherwise)	+
Summer rainfall onset	Dummy (1 if there was, 0 otherwise)	-
Harvest time rainfall	Dummy (1 if there was, 0 otherwise)	+
Disease and pest	Dummy (1 if there was, 0 otherwise)	+
Cropland	Continuous (hectare)	-
Age of the head	Continuous (years)	-
Farm labor	Continuous (numeric)	+
Education of head	Continuous (numeric)	+
Credit access	Dummy (1 if they have, 0 otherwise)	+
Crop residue	Dummy (1 if there was selling, 0 otherwise)	+
Off-farm	Dummy (1 if they have access, 0 otherwise)	+
Livestock holding	Continuous (Numeric)	+
Inflation	Continuous (Indexed value)	-

4. RESULTS AND DISCUSSION

This chapter presents the results and discusses the core findings of the study. It has sub-sections in which the first part covers descriptive results about common and individual characteristics like socioeconomic, production inputs, crop yield, income and other aspects of the sample smallholders in the two farming systems. The second sub-sections present econometric results and discussion about effect of climate variability on cereal yield, crop income and rural labor displacement, and it further discusses results of the study in comparison with the findings of related previous studies.

4.1. Descriptive Analysis

4.1.1. Socioeconomic Characteristics

Smallholders in the two farming systems had significant difference in most of the covariates considered to describe sample households (Table 9). Households in Arsi grain plough farming system had relatively larger household size (more than six persons per household) as compared to the central highlands (5.30 per household). This indicates that farm households in the two farming systems may have significant difference in human labor available for the crop production. Household size of the overall sample smallholders showed successive reduction with the going of time (Appendix Table 2). There were small variations in few sample years like in 1997 for smallholders from central highlands and in 1999 for Arsi grain plough farming system. Total average family size of sample households from Arsi grain plough farming system was larger than central highlands, which may result in having densely populated area in the former farming system. Family size variability among sample smallholders in a given year was higher in Arsi grain plough farming system. Bartlett's test of variance equality showed

that household size variability between Arsi grain plough and central highlands farming system was significantly different having $\chi^2 = 43.99$ and P-value of 0.000. Based on the test there was significant family size variation among households within the two farming systems having $\chi^2 = 23.66$ and 25.18 for central highland and Arsi grain plough, respectively.

Table 9. Summary of covariates for the two farming systems

Covariates	Central highland	Arsi grain	Combined Mean	t-value
Household size	5.30	6.36	5.67	12.813***
Age of household head	52.32	48.62	48.61	5.983***
Fertilizer (kg)	89.55	35.17	70.71	10.704***
Total seed usage (kg)	44.73	8.83	29.00	5.351***
Number of oxen	1.18	0.81	1.05	9.961***
Livestock hold (TLU)	5.02	3.78	4.59	9.072***
Total cropland (ha)	1.99	1.96	1.98	0.597
<i>Teff</i> land (ha)	0.715	0.549	0.634	6.593***
Maize land (ha)	0.211	0.610	0.467	11.555***
Wheat land (ha)	0.425	0.479	0.444	3.567***
<i>Teff</i> yield (kg/ha)	979.57	621.63	820.90	13.056***
Barley yield (kg/ha)	939.56	978.72	950.81	1.001
Wheat yield (kg/ha)	1068.56	1262.20	1134.97	3.489***
Maize yield (kg/ha)	1183.06	1174.82	1177.14	0.041
Sorghum yield (kg/ha)	697.61	1252.04	783.98	6.354***
Crop income in Birr	1256.50	1520.53	1347.55	2.013**
Crop season rainfall	866.62	630.28	785.14	26.423***
Crop season temperature	21.75	26.76	23.47	62.741***
Non/Off-farm income	163.17	212.29	180.10	2.811***

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

Source: Own computation, 2016

The ERHS data revealed that most sample smallholders had an economically active head, with a significant difference between the two farming systems (Table 9). Age of the head among smallholders in central highland showed significant difference across time and households with t-value of 24.73, but for Arsi grain plough, there was no significant difference (t-value of 0.249). However, the two farming systems had relatively larger cropland (1.98ha) as compared to the national level (1.25ha) reported by CSA (2015) while there was no significant difference between them. Based on Table 9, smallholders of the two farming systems had significant difference in their crop yield except for barley and maize. In general, smallholders in the two farming systems had significant variation in most of the covariates considered in Table 9.

4.1.2. Cropland Allocation and Yield

Post-harvest survey in 2015 indicated that cereals took 81% and 87% of the total cropland allocation and overall production of the country, respectively (CSA, 2015a). The survey showed that *teff*, maize, sorghum, wheat and barley covered 24.02%, 16.80%, 14.58%, 13.25% and 7.81% of the cropland, respectively. The national average cropland holding was 0.88ha per household in 2015/16 production year. Given this, cropland allocation of smallholders in central highlands farming system was higher than Arsi grain plough for some production years especially before 1999 (Table 10). Land allocated for crop production in the two farming systems showed consistent increment from 1993 to 1997 production years, but there was drastic change after 2004 that may be due to introduction of land redistribution program in the country. Because of this circumstance, cropland allocated in 2009 production year was lower than the amount what it was in 2004 for smallholders in the two farming systems. Land redistribution program may be the reason for the drastic reduction of cropland in central highlands farming system after 2004 production year. Recall data collected by ERHS indicated that long run cropland allocation of some farm households in central highland farming system of Ethiopia was below 1 ha before 1989, but there was increment onwards that year.

Based on Table 10 the overall average cropland allocation of smallholders in the two farming systems was equal in most of the production years except 1999 and 2009. Cropland ownership among farm households within each farming system had significant difference having $\chi^2 = 52.522$ and 46.86 for Arsi grain plough and central highland farming system, respectively.

Table 10. Household's cropland allocation in the two farming systems (in ha)

Year	Central highland	Arsi grain plough	Combined Average	t-value
1994a	2.01	1.91	1.98	0.354
1995	2.34	2.01	2.23	1.46
1997	2.29	2.16	2.25	0.991
1999	1.69	2.13	1.84	4.353***
2004	2.35	2.15	2.28	1.345
2009	1.41	1.79	1.55	4.627***
2014	1.54	1.46	1.51	0.737
Overall Average	1.898	1.926	1.908	
Overall Std. Dev.	1.483	1.445	1.470	

Within Std. Dev.	1.047	0.829	0.977
Between Std. Dev.	1.073	1.208	1.120

Note: *** represent 1% level of significance

Source: ERHS (1994a-2009) and own survey, 2014

The variation in cropland allocation among smallholders was relatively larger in Arsi grain plough as compared to central highland farming system. Individual household's yearly cropland allocation variation was relatively larger in central highland as compared to Arsi grain plough farming system. Table 11 shows the probability of changing the cropland allocation of smallholders from budgeting below 2ha to more than it within the ten production years (from 1999 to 2009) interval. In connection to this, sample smallholders had 39.75% probability of allocating below 2ha cropland even after ten years in 2009. Smallholders that allocated more than 2 ha cropland in 1999 had 60.25% probability of remaining within that amount after ten years in 2009. Smallholders in central highland and Arsi grain plough, respectively had probability of 38.34% and 42.43% to have cropland of below 2ha even after ten years in 2009, wherein households in the former farming system had more variable land allocation.

Table 11. Probability of changing the cropland allocation

Description	Years	Overall		Central highland		Arsi grain	
		1999	2009	1999	2009	1999	2009
Below 2 ha	1999	50.99	49.01	37.76	62.24	64.56	35.44
	2009	34.88	65.12	38.50	61.49	25.63	74.37
	Total	39.75	60.25	38.34	61.66	42.43	57.57
Below yearly average	1999	71.72	28.28	68.18	31.82	80.20	19.80
	2009	36.21	63.79	51.85	48.15	14.43	85.57
	Total	57.39	42.61	62.33	37.67	47.98	52.02

Note: Values in the table are in percentage

Source: Own computation from ERHS (1999 and 2009), 2017

Based on Table 11 smallholders had 57.39% probability of budgeting below overall (average of the sample households) yearly average cropland in 2009. Smallholders in the two farming systems had 28.28% probability of shifting from having below the overall yearly average cropland to more of it after ten years. Similarly, smallholders in the two farming systems had 71.72% probability of budgeting equal amount of cropland after ten years in 2009.

Smallholders in central highland had relatively better probability of changing their cropland allocation in the ten years interval from 1999 to 2009, in which they had 62.24% probability of transition from budgeting below 2ha cropland while smallholders from Arsi grain plough had only 35.44%. Smallholders from central highland had 31.82% probability of transition from having below yearly overall (average of the sample households) average; smallholders in Arsi had only 19.80% probability of shifting. This circumstance indicates that farm households in central highland had better probability of changing their cropland allocation.

Teff is the dominant cereal crop of the country in terms of cropland and second to maize in terms of production. Similarly, *teff* took the leading position in cropland coverage in the two farming systems (Appendix Table 8). Maize and wheat took the second and third position in cropland coverage in Arsi grain plough farming system, whereas barley took the second position in central highland. Appendix Table 11 showed that households that budgeted cropland of below the overall yearly average for producing *teff*, maize and wheat in 1999 had 85.17%, 40.46% and 53.57%, respective probability of remaining below that level even after ten years in 2009. This indicated that there was lower variation in land allocation for *teff* as compared to the other cereals since more than 85% of the sample smallholders had similar cropland allocation for this crop. The table also showed that there was better probability of transmission in cropland allocation for *teff* (40.76%) and maize (50.75%) as compared to wheat (19.54%).

Ethiopian overall grain production showed a remarkable enhancement of 102.06% in 2015 from what it was in 2006, exactly ten years later (CSA, 2015a). This significant change was mainly due to cultivated land increment as to the report of the agency. Overall yield of *teff* was significantly different in the two farming systems, wherein households in central highlands were better productive. Both production and yield of wheat was significantly better in Arsi grain plough farming system (Table 12). The table revealed that most of the yearly average cereal yield was better in central highlands farming system as compared to Arsi grain plough except for maize in which the latter farming system performed better. Maize yield consistently increased in the two farming systems starting from 1999. Households in central highlands farming system were better productive in producing *teff* than Arsi grain

plough and the reverse happened for maize. The test result showed that *teff* and barley yield exhibited significant difference between the two farming systems having P-values of 0.003 and 0.004, respectively. *Teff* yield difference of the two farming systems consistently narrowed from the first to the last sample survey year. Households in the two farming systems had no significant difference in maize yield (t-value = 0.041) for the sample survey years even though farmers in Arsi grain plough had relatively better yield. There was relatively narrow gap between yield of wheat and barley in central highland farming system as compared to the difference in Arsi grain plough. Overall difference of the two farming systems in wheat and barley yield was lower as compared to the gap for *teff* and maize production. Both wheat and barley yield showed better and successive improvement in central highlands than Arsi grain plough farming system after 1999. Wheat and barley responded similarly for each variation in production inputs that may be artificial or natural ones, and there was relatively higher yield variability in the two farming systems for few years like 1997 and 2014.

Table 12. Crop yield (qui/ha) trend in the two farming systems

Year	Central highland				Arsi grain			
	<i>Teff</i>	Wheat	Maize	Barley	<i>Teff</i>	Wheat	Maize	Barley
1994a	8.74	9.02	7.84	11.87	3.71	8.96	10.12	10.44
1995	8.36	8.03	9.95	11.70	5.04	9.70	13.56	9.42
1997	9.93	12.16	11.24	9.95	5.97	15.56	15.55	12.42
1999	9.49	11.12	6.78	10.29	4.96	9.21	11.60	10.04
2004	10.16	11.82	10.19	9.88	6.73	11.04	13.88	8.69
2009	9.12	12.37	14.60	13.73	6.62	13.08	17.74	11.86
2014	13.77	20.91	17.42	23.22	11.88	14.60	22.23	11.79
Overall average	9.81	10.69	11.72	9.40	6.22	12.62	11.75	9.80
Overall Std. Dev.	6.68	9.14	11.30	7.80	6.10	8.70	12.04	7.01
Within Std. Dev.	5.62	7.41	8.87	6.50	4.98	6.37	9.45	5.10
Between Std. Dev	3.76	5.76	7.60	5.03	5.03	6.31	8.58	5.05

Source: ERHS (1994-2009) and own survey, 2014

Yield variation for sample households in the two farming systems happened in most cases at the same year for instance in 1999 there was yield reduction for all crops and this overall reduction also happened in 2009 exactly after ten years for cereals like *teff*. Sampled households from the two farming systems had lower wheat, maize and sorghum yield for each of the sample years as compared to the national level (Appendix Table 9). The gap between the national level and the two farming systems for wheat and sorghum was increasing starting

from 1997. There was similar circumstance for *teff* yield though the two farming systems had better performance in 1994a and 1997. Variation of maize yield was high in the two farming systems compared to the other cereals. Both within and between smallholders variation were relatively high for maize followed by wheat yield (Table 12). *Teff* yield had the lowest relative variation in the sampled survey years.

Smallholders that had *teff*, maize and wheat yield of below the overall average in 1999 had 59.24%, 49.25% and 80.46% probability of remaining below the average level even after ten years (Appendix Table 11). Majority (71%) of the smallholder households in the two farming systems had *teff* yield of lower than the national average level in 1999 and many of them remain below that even after ten years in 2009. The rate of transition to produce more than the national level was lower for the sample smallholders in the first (25%), second (28.88%) and third (24.55%) ten production years gap (Table 13). Smallholders' transition to production level of more than the national average was better for maize (38.94%, 36.31% and 30.06%) and wheat (34.98%, 35.60% and 36.36%) yield as compared to *teff* (25.00%, 28.88% and 24.55%) in the three respective ten years interval presented below.

Table 13. Probability of smallholders' to produce more than the national level

Intervals			<i>Teff</i>		Maize		Wheat	
			1995	2004	1995	2004	1995	2004
1 st ten years		1995	75.00	25.00	61.06	38.94	65.02	34.98
		2004	55.36	44.64	44.00	56.00	26.84	73.16
		Total	63.66	36.34	48.97	51.03	40.75	59.25
2 nd ten years		1999	71.12	28.88	63.69	36.31	64.40	35.60
		2009	47.51	52.49	41.83	58.17	38.18	61.82
		Total	58.33	41.67	50.25	49.75	46.88	53.13
3 rd ten years		2004	75.45	24.55	69.94	30.06	63.64	36.36
		2014	53.25	46.75	42.33	57.67	58.00	42.00
		Total	64.29	35.71	56.55	43.45	59.95	40.05

Note: The values are in percentage

Source: Own computation from ERHS (1995 and 2004), 2017

4.1.3. Crop Yield, Income and Rainfall Variability

Average crop seasonal rainfall of central highlands farming system was higher for all the production years as compared to the other farming system, and it showed greater inconsistencies registering the highest amount in 2010. Average crop season rainfall level difference between the two farming systems was becoming wider in recent years, mostly after 2006. There was cyclical type of movement in rainfall of central highlands farming system having reduction within three to five years of interval. Though it was not clear enough like the central highlands, rainfall trend of Arsi grain plough also had cyclical type of movement to some extent and exhibiting extreme reduction in few years like 2002 and 2012 (Figure 8).

Fractional variation in one of the climate elements would have devastating effect on the productivity and overall future of Ethiopian crop production. A study conducted by Lobell *et al.* (2011) argued that cereals' yield would decline by 10% in 2050 nearly in all SSA countries due to rainfall inconsistency. Since Ethiopian crop production is purely rain-fed type every variation in either rainfall or temperature, or two of them together would significantly affect smallholders' crop yield. Dercon and Hoddinott (2011) also found that the harvest in 1993 at the main cropping season was very low and the worst for some households in Arsi grain plough as compared to the previous five years. The authors showed that the poor distribution of rainfall in the two farming systems was the main reason behind huge *teff* yield reduction. Households in the study area were suffering from each type of rainfall inconsistency to a great extent during the production year (2009). Some of the problems were related to the rainfall condition including inconsistent availability and frequent shortage in the main cropping season. For instance, many households in the two farming systems were suffering from harvesting season rainfall in 2009 production year (Appendix Table 6).

Teff yield was lower in 1999 and 2009 compared with the respective preceding production years that may be because of severe weather variation (Appendix Table 11). Growing season rainfall inconsistency and insufficiency may be the reason behind those drastic yield reductions. Response of sample households indicated that *teff* was the one highly damaged by rainfall inconsistency in 1999 and 2009 production years on which there was not balanced rainfall for the growing period (Appendix Table 6). *Teff* resists moderate drought, but mostly it required good rains at least during the early growth, flowering and seed-setting stages of the

crop (Abuhay *et al.*, 2001). Cropping season rainfall and temperature (dominant elements of climate variability) are the most important inputs in the crop production system, in which increment of the latter one may reduce yield and quality of food-crops (Joshi *et al.*, 2011).

Rainfall inconsistency in the onset and cessation period showed greater variation when one compares what it was in 1999 and 2009 after 10 years as per the data collected by ERHS. Rainfall inconsistency and other climate variability elements may be the main reasons for the lower crop production. Based on the data collected by ERHS in 1995 rural households suffered from problems related to climate and weather variability in which 34.4% of the household who produce wheat were affected moderate to severe extent. This resulted in drastic yield reduction for some households in central highlands farming system. However, degree of reduction in wheat yield was not severe like *teff* in 1999 for some households of the two farming systems. Maize productivity levels on commercial farms in Ethiopia reach 4 tons/ha, showing that still there is a room for increasing productivity of smallholder farmers (currently they produce 2.5 tons/ha) if improved seed and fertilizer are used (Abu, 2013). This indicates that there is significant gap between the potential level and actual amount due to factors that may or may not be related to climate variability. Heavy rainfall and frost during the growing season were main reasons behind the yield reduction for some households in central highlands farming system.

In some spring seasons, there was not enough rain and many smallholders did not plant crops especially in central highlands as to ERHS data. Sample smallholders replied that spring season production was risky because of variability, delay or absence of rainfall. The spring season rainfall was highly unreliable that showed greater variability and sometimes there was complete absence of it for households in the two farming systems; and in some years, the rain was available only for few weeks and result in loss of spring crops (Dercon and Hoddinott, 2011). The authors found that the harvest in 1994 was not enough to feed smallholders' family in D/Birhan *kebele* of the central highlands farming system. Cropping season temperature of Arsi grain plough farming system was consistently higher than the central highlands. Some ups and downs happened more frequently in the latter farming system than the former one.

Cropping season temperature of sample sites in the two farming systems showed significant variation having P-value of 0.004.

Spearman correlation coefficient of *teff* yield and cropping season rainfall showed that there was insignificant but negative correlation having P-value of 0.43 and 0.48, respectively for central highlands and Arsi grain plough farming system. On the contrary, there was significant correlation between wheat yield and cropping season rainfall having P-value of 0.094 in central highlands farming system. Asha *et al.* (2012) showed that rainfall reduction, pests and diseases outbreak, and temperature changes were the major reasons for yield reduction in Dharwad district of India. In the same fashion, many smallholders in Arsi grain plough farming system faced insufficient rainfall for the crop production and this result in server crop damage on few production years. Each aspect of rainfall condition happened with high frequency wherein overall rainfall shortage and poor distribution were the most frequent ones in the area that miffed many of the smallholders.

Maize yield had significant negative correlation with rainfall in the two farming systems having P-value of 0.000 and 0.007, respectively in central highlands and Arsi grain plough farming system. Smallholders in central highlands farming system reported that sorghum was the second most miffed crop because of rainfall inconsistency (Appendix Table 6). In this farming system, many smallholders lost part of their potential sorghum produce due to rainfall inconsistency in 1999. Discussion with focal persons in the central highlands farming system indicated that there was production of short seasoned crops in springseason before 15 and 20 years, but recently it is not possible to do that due to rainfall inconsistency. Currently, households of the area produce crops only in the main crop season, summer, because of spring rainfall inconsistency.

Table 14 showed probability of rainfall inconsistency for each sample cereals in the two farming systems, wherein the problem was serious for wheat and maize production. The problem had significant probability (85.33% and 77.29%) of occurrence in ten years interval for the two crops. There was similar probability of harvesting time rainfall (76.06%) for *teff* and maize production in 2009 after they were in the problem before ten years in 1999. The

probability of having normal summer rainfall after the inconsistency before ten years was relatively higher for barley (72.88%) and *teff* (69.83%) production. The two crops also had significant probability of suffering from harvesting time rainfall in both 1999 and 2009. *Teff* was more susceptible to the rainfall inconsistency than other crops, in which more households in central highland suffered in both 1999 and 2009 survey years (Table 14). The number of households affected by rainfall inconsistency increased in 2009 production year especially those who produce *teff* and wheat.

Table 14. Probability of rainfall inconsistency for each crop

Crop type Affected	Year	Summer rain inconsistency		Harvesting time rainfall	
		1999	2009	1999	2009
<i>Teff</i>	1999	30.17	69.83	76.06	23.94
	2009	22.71	77.29	59.40	40.60
	Total	25.98	74.02	65.20	34.80
Wheat	1999	85.33	14.67	77.03	22.97
	2009	73.13	26.87	64.49	35.51
	Total	81.08	18.92	67.71	32.29
Maize	1999	77.29	22.71	76.06	23.94
	2009	69.83	30.17	59.40	40.60
	Total	74.02	25.98	65.20	34.80
Barley	1999	27.12	72.88	80.60	19.40
	2009	14.93	85.07	68.81	31.19
	Total	19.78	80.22	72.36	27.64
Sorghum	1999	26.82	73.18	66.98	33.02
	2009	29.55	70.45	77.14	22.86
	Total	28.17	71.83	70.99	29.01

Source: Own computation from ERHS (1999 and 2009), 2017

Crop income of households in the two farming systems was very low before 2004 that may be due to reduction either in quantity produced or output price wherein both of them were lower as compared to the recent level in 2014. In 1994a households in Arsi grain plough farming system collected better crop income as compared to central highlands. Crop income of households in the former farming system had improved after 1997 with a different rate of increment. Though there was slow crop income increment in the two farming systems after 1995 but the level was better in Arsi grain plough up to 2009. Crop price increment starting from 2008 may be the reason for the sharp income increment in central highlands farming system where most of the *kebeles* are near to the central market.

There was statistically significant difference in smallholders' crop income in the two farming systems (P-value of 0.044) across the sample production years. Bartlett's variance equality test revealed that there was statistically significant (P-value = 0.000) crop income variability for households in the two farming systems. Overall average crop income of smallholders in central highlands and Arsi grain plough farming system was 1258.98 *Birr* and 1521.45 *Birr* with a standard error of 4802.05 and 2861.49, respectively for the whole panel period. Smallholders in Arsi grain plough had relatively stable and better crop income. The average overall crop income of smallholders in central highlands was lower and had relatively larger standard deviation for both within and between household level.

Table15. Yearly crop income of smallholders in the two farming systems

Year	Central highland	Arsi grain plough	Combined mean	t-value
1994a	469.96	685.51	541.81	-2.62**
1994b	413.70	802.41	543.28	-8.47***
1995	450.37	502.00	467.58	-4.16***
1997	670.85	1070.81	804.17	-5.76***
1999	635.15	985.59	751.96	-4.30***
2004	784.58	1215.61	928.26	-4.63***
2009	2908.29	3300.00	3104.15	-4.65***
2014	5800.00	3600.00	4700.00	6.10***
Overall mean	1258.98	1521.45	1349.49	
Overall Std. Dev.	4802.05	2861.49	4236.06	
Between Std. Dev	2696.82	1382.86	2339.58	
Within Std. Dev.	4259.85	2566.97	3762.82	

Note: *** and ** indicate 1% and 5% level of significance, respectively

Source: ERHS (1994a-2009) and own survey, 2014

Figure 6 reveals relatively strong similarity between crop income and yield trend in each survey year, which implies that each change in crop income is highly correlated with yield variation. This argument could lead to have one inference, which is “factors that affect yield would have induced effect on households' crop income”. Climate variability elements that affect yield would cause crop income variation for smallholders in the study area. There was narrow gap between yield and crop income collected before 2004 on which the two were equal. After 2004 the gap between them became wider and having drasting increment in crop income that may be due to crop price rise. The recent (especially after 2004) crop income

variability may be sourced from crop price variation as to Figure 6. Considering the similar trend of the two lines it is simple to conclude that crop income variability is not only sourced from price but it may be also from yield variation.

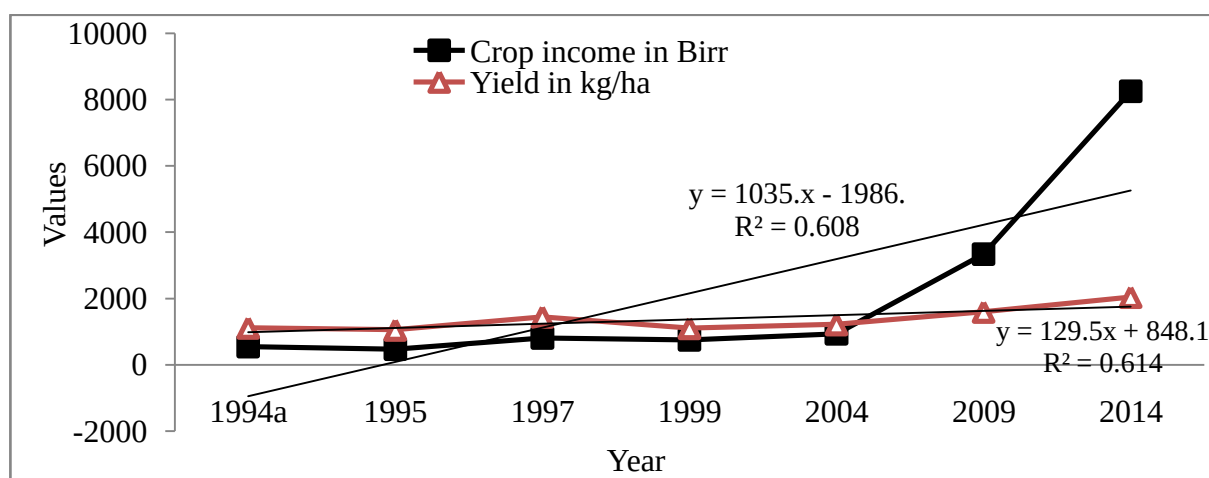


Figure 6. Average crop income and yield trend

Source: ERHS(1994a-2009) and data collected by the researcher, 2014

Relatively crop yield for households in central highlands was stable up to 2009 as compared to the other farming system in which there was ups and downs years like 1997 and 1999 (Figure 7). Crop income of households in Arsi grain plough farming system had similar trend with yield up to 2004 production year on which crop income showed drastic increment though there was no yield variation. Crop price rise may be the main reason behind the drastic crop income increment in the two farming systems after 2004 where price rise may in turn be sourced from other factors. Simple correlation coefficient between yield and income showed that there was strong correlation having P-value of 0.000 and 0.036 for central highlands and Arsi grain plough farming system, respectively.

Findings of Julie and Corene (2014) revealed that in a period where monthly rainfall is inconsistent, most households experienced agricultural income reduction. Similar circumstances happened in the two farming systems of Ethiopia wherein rainfall availability showed frequent variation in each sample production year. Though there was subsequent cropping season rainfall reduction starting from 1999 production year, the crop income exhibited continuous increment in central highlands. At the medium rainfall level in 1995 and

2004 production year, crop income was relatively better, which result in positive interaction between crop income and rainfall level for those years.

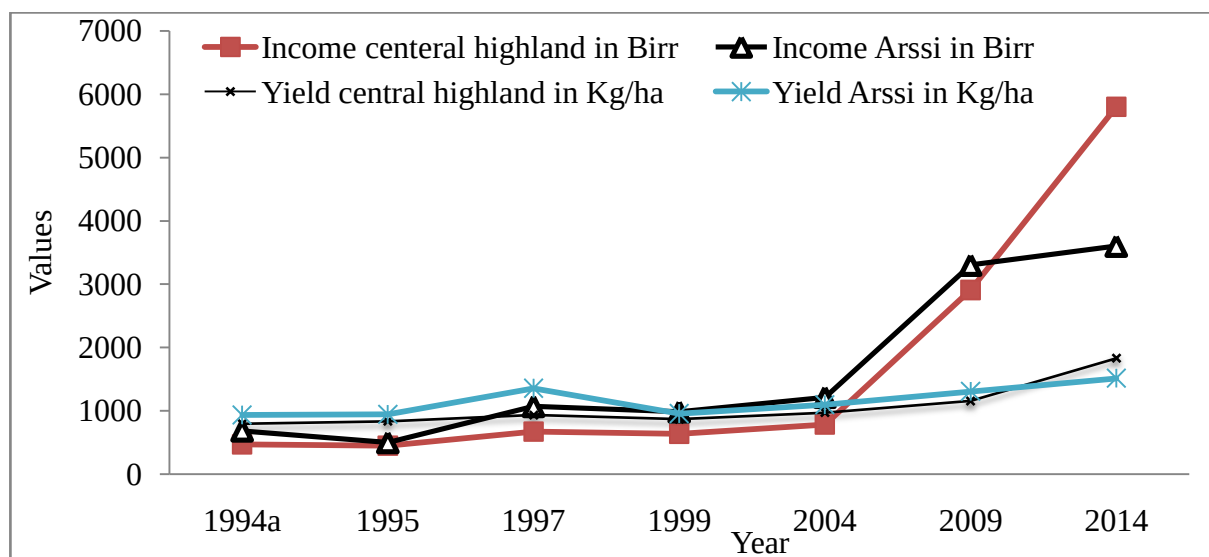


Figure 7. Trend of crop yield and income in the two farming systems
Source: ERHS(1994a-2009) and data collected by the researcher, 2014

Average cropping season rainfall of the two farming systems showed similar trend starting from 1994a to 2014, and the variations happen at the same production year. Even though cropping season rainfall of the two farming systems was lower in 1997 production year as compared to years both before and after this, the crop income collected was better. Crop income was better while the rainfall level was low in 1995, 1997 and 2004. The higher rainfall level in 1994 and 1999 production years resulted in lower crop income as compared to other years like 1997 and 2004. Clear negative relationship between crop income and rainfall variability exhibited for production years from 1994 to 2004.

The rainfall level of 1997 and 2004 production year was relatively similar, and the yield and crop income were better. In the same fashion, rainfall level of 1995 and 2009 was relatively at similar level, crop yield reduced while crop income increased sharply in the latter production year that may be due to crop price rise sourced from different factors. This logic of relating crop price and climate variability could be strengthened if one considered 1999 survey year on which crop yield reduced drastically as compared to 2004 but the crop income was better.

Figure (6 and 8) revealed inverse relationship between cropping season rainfall and crop income for majority of the sample years.

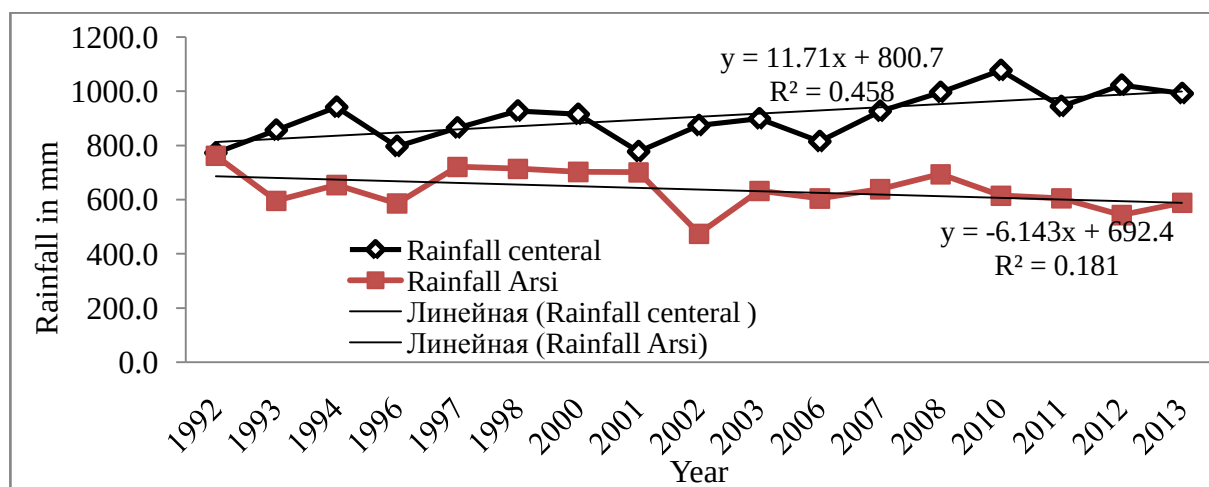


Figure 8. Crop season rainfall of sample farming systems
Source: ENMA, 2014

4.1.4. Adaptation Strategies to Climate Variability

Adaptation strategies include crop switching, irrigation, or investments on enhancing soil fertility may help to mitigate production losses due to climate variations (Christopolos, 2010). Understanding factors associated with patterns in farm level changes is important since policies aimed at facilitating adaptation typically implemented at scales greater than individual household and community level (Stephen *et al.*, 2014). Currently, climate variable adaptation receives great attention and sometimes people all over the world develop their indigenous strategies to reduce effect of the problem. Their experience can be helpful in designing appropriate policies for climate change and variability. Households in the study area from their indigenous knowledge adopted strategies such as changing planting dates and using different variety of seeds to make yields less susceptible to climate variability. Since climate variability may affect communities differently, they tend to possess different adaptive capabilities and strategies.

Soil moisture supplementing methods like shallow and hand-dug wells in dry-season, and moisture improvement techniques like semi-moons and mulching are efficient methods to use

water through drip irrigation (Stephen, 2009). The author identified that choice of drought-resistant varieties, high-value crops, irrigation efficiency improvement and using better water technologies are methods that have been tried by smallholders as adaptation strategies to combat climate variability in some African countries. Different communities depending on their adaptive capacities developed their own coping strategies (Stephen, 2009) to reduce effect of climate variability. Depending on risks and vulnerability, smallholder farmers logically made certain adjustments on technologies and agricultural production system choices. Previous studies argued that asset-holding improvement would be associated with better adaptation potential (Stephen *et al.*, 2014). Households in the two farming systems practiced agro-forestry, crop rotation and rainwater harvesting based on their traditional knowledge to adapt climate variability.

The data collected in 2014 showed that some households adopt two or more strategies in one season to acclimatize climate variability. About 29.43% of households replied that there were some crops produced in previous times but they could not be able to produce them currently due to rainfall variability and temperature increment above optimum of the crops. Majority of them (53%) replied that rain shortage for the cereal production happened in grain filling stage and the remaining 29.81% replied that it happened at the beginning of crop production season. Even though they were not frequent like the previous two cases, few areas suffered from rain shortage at germination time (7.06%) and flowering stage (5.49%) of the crops. Rainfall shortage in grain filling stage of cereals was critical problem that result in serious damage as to households' response. Rainfall instability at the beginning time was also a threat to crop production in the two farming systems. Households in central highlands farming system practiced check-dam construction (75.14%), changing the crop type (11.43%) and water harvesting (11.43%) if they expect heavy summer rain.

Smallholders in the study area respond for late start of rain by changing sowing season (50%) and crop type (35.37%). If there was no rain at the right time, 49.01% of the sample households shift sowing time, 37.39% change the crop, 6.80% increase the fertilizer application and 4.82% adopt supplementary irrigation. If there was early cessation of crop season rainfall, 44.35% of the households did water harvesting, 20.34% re-cultivate the cropland, 18.07%

supplement via irrigation and 14.12% change their occupation to have additional income. Households took different measures like changing the sowingtime (48.57%), adopting new technologies (28.86%), switching to other crops (19.71%) and practicing off- and non-farm activities (2.86%) to cope the effect of climate variability in general. Households mainly used local seed varieties because of their better adaptation to climatic conditions of the area (Akker, 1998). Most households in areas that suffer from frequent moisture stress forced to look for means of supplementing the rainwater and participated in water-harvesting programs. For instance, more than 62.5% of the sample households in this study implemented water-harvesting technologies to cope up with moisture stress problem in 2009.

Frequent erosion and continuous cultivation of the cropland were the two most common source of soil fertility reduction in the two farming systems. Some households increased usage of modern inputs in 1999 as compared to their previous allocation, though they did not continue consistently in recent times. Because of non-affordable price for purchasing inputs, many households in the study area did not apply the recommended rate of fertilizer and other modern inputs in their crop production. About 70% of smallholders, who adopted fertilizer, faced a problem of input price rise. As to the view of respondents, there was continuous fertilizer price rise especially in recent times. According to FAO (2004), SSA's fertilizer consumption is not expected to rise significantly in the next two decades. Households in some places replied that, the price is becoming more than their capacity to purchase and they were unable to pay the amount charged. Due to this problem, many households reduced their fertilizer consumption and apply lower amount than the recommended rate.

Besides price increment, smallholders in the two farming systems also suffered from soil and/or climate incompatibility problem and fear of risk was the other reason for usage of less modern inputs. More than 62% of sample households in 2009 applied different types of soil conservation mechanisms to keep cropland fertility (Appendix Table 7). Because of labor shortage and limited skill to implement, some households did not practice soil conservation strategies on their cropland in 1999 and 2009 production years. Smallholders of the area had limited awareness about productivity enhancement mechanisms. Stephen *et al.* (2014), hypothesized that access to information is associated with increased adaptation probability.

About 30% and more than 50% of sample households practiced irrigation and soil conservation, respectively on their cropland in 2004 production year (Appendix Table7). About 48% and 24% of households respectively adopt stone and soil bunds indigenous methods and there was counter plough for soil conservation. Some sampled households (30%) participated in water harvesting as an adaptation strategy to the ongoing climate variability. Majority (69.67%) were not participant in this activity because of consistent crop season rainfall in 2004 production year.

Smallholders in the two farming systems adopted new variety of crops starting from 1993. There were production of vegetables, coffee, *khat*, fruit, sugarcane and other cash crops in central highlands farming system. Few households participated in producing one or more of the aforementioned crops wherein majority of them produced coffee, banana and *khat* in 1994a. Smallholders in the two farming systems tried to compensate each cereal production variation through having additional income sourced from cash crops. Smallholders in Arsi grain plough farming system emphasized on producing root crops like *enset* and potato in 1994a (Table16). Households in this farming system had better diversified income sources, which may enable them to adapt to climate variability.

Table16. Number of households adopted new crops

Description	Central highlands				Arsi grain plough			
	1994a	1997	1999	2004	1994a	1997	1999	2004
Stimulant crops	25	16	40	17	70	39	3	50
Vegetables and Fruits	193	30	33	39	165	6	4	51
Root crops	68	55	71	1	181	72	3	60
Tree crops	79	219	72	288	98	63	158	73
New variety of cereals	49	0	0	0	0	0	0	0
Total	414	320	216	345	514	180	168	234

Source: ERHS in 1994a, 1997, 1999 and 2004 survey year

Large number of households in central highlands farming system adopted tree crops as one source of income in 1999 and 2004 production years. More households in Arsi grain plough farming system adopted new crops as an additional income sources in 1994 production year, but the number reduced in 1997, which may be due to moisture stress. Households of the two farming systems adopted new variety of wheat and white *teff* because of better yield and revenue compared to other cereals. Those newly adopted crops generate more revenue than the

indigenous ones. New variety of wheat had better acceptance by smallholders in central highlands because of better yield and quality of the produce, which guaranteed attractive price. More than half of the sample smallholders adopted new hybrid crop varieties in 2014 for productivity (44%), market (24.64%) and drought resistant (19.81%) capacity.

More than half of the smallholders in the two farming systems adopted strategy_1, _2 and _4 (See Table 17). Table 17 revealed that smallholders who adopted strategy_1 and _3 collected lower average crop income than the non-adopters. However, the standard deviation of the latter group was relatively high implying that households who were non-adopters of short-run strategies collect better crop income with greater uncertainty. Adopters of long-lasting strategies (2 and 4) generated better crop income as compared to the non-adopters of those strategies. There was significant difference in the average crop income collected by adopters and non-adopters of each strategy (Table 17).

Table 17. Average crop income of adopter and non-adopter households

Strategies	Description	Household (%)	Crop income	Stan. error	t-value
1 (Changing sowing time)	Non-adopters	38.46	8822.84	12957.97	1.77**
	Adopters	61.54	6746.38	8605.31	
2 (Technology adoption)	Non-adopters	34.00	4066.43	5993.04	-5.93***
	Adopters	66.00	9336.62	11842.31	
3 (Alternative income sources)	Non-adopters	57.32	8345.80	11174.29	1.82*
	Adopters	42.68	6469.56	9518.82	
4 (Conservation strategies)	Non-adopters	44.91	5217.27	8197.41	-4.23***
	Adopters	55.09	9442.87	11783.11	

Note:***, ** and * indicates 1%, 5% and 10% level of significance, respectively

Source: Own calculation, 2016

Smallholders that adopt long lasting (technology adoption and conservation) strategies earned better crop income with higher variability as compared to adopters of short-run (changing sowing time and alternative income sources) strategies. Shifting from adopting short-run strategies to the long lasting ones need a risk taker households. However, if smallholders of the two farming systems are risk averse they may keep themselves in adopting short-run strategies since the long lasting ones are with significant uncertainty. Shifting from adopting one strategy to the other would be dependent on risk behavior of smallholders.

4.1.5. Participation in Off-and Non-farm Activities

Whenever a farmer has free time from agricultural tasks, s/he will engage in off-farm activities (Dercon and Hoddinott, 2011) as an alternative source of income. Smallholders in the two farming systems engaged in different non- and off-farm activities (Appendix Table 10) to supplement their main source of income, crop production. Few households from central highlands farming system participated in different off- and non-farm activities like fire wood collection, charcoal production, preparing traditional drinks, petty trade and other sources, and they had collected 119.25 *Birr* that was approximately 25% of the crop income by the time. Many of the smallholders in central highlands farming system participated in petty trade and firewood collection, and generated 97.5 and 113.80 *Birr* respectively in 1994a. About 45% of sample smallholders in Arsi grain plough participated in off- and non-farm activities in the initial ERHS and collect income of 394 *Birr* that was better than the net income from the main economic activity, crop production. Firewood collection was the principal non-farm source of income for relatively poorer smallholders in Arsi grain plough farming system.

Smallholders' participation in off-and non-farm activities showed variation in some of the survey years, wherein the movements were highly related to crop yield and income. Relatively larger number of smallholders from central highlands farming system participated in off- and non-farm activities in 2004 that may be due to *teff* yield reduction. Active participation of households may be exact mirror image of cereal yield variation. Cereal yield increased in 2014 for smallholders in Arsi grain plough farming system, which may be the reason for lower participation of them in non- and off-farm activities.

Table18. Probability of participation in off-farm activities

First ten years			Second ten years			Third ten years		
Year	1993	2004	Year	1999	2009	Year	2004	2014
1993	64.67	35.33	1999	69.70	30.30	2004	75.48	24.52
2004	58.87	41.13	2009	72.76	27.24	2014	67.05	32.95
Total	63.38	36.62	Total	71.18	28.82	Total	71.65	28.35

Source: Own computation from ERHS(1994a-2009)

Table18 showed that smallholders in the two farming systems had lower probability of off-farm participation in the three ten years intervals. The probabilities of being non-participant were higher in the above three grouped years having the largest (71.65%) in the third one. Most of the non-participants had significant probability of remaining as it is even after successive ten years. Smallholders that did not participate in 2004 had 75.48% probability of being non-participant in 2014 exactly after ten years. Table18 shows that smallholders in the study area had relatively large probability (72.76%) of being non-participant in 2009 while they were in 1999 before ten years. The above table revealed that probability of participation after ten years of being non-participant showed successive reduction from the first ten years interval to the third (from 64.67% to 69.70% and from 69.70% to 75.48%).

Table19. Off-and non-farm income of households in the two farming systems

Description	Central highland	Arsi grain plough	Combined average	t-value
1994a	170.05	179.26	174.36	-0.25
1994b	244.14	334.97	277.46	-2.04**
1995	268.80	421.78	340.54	-1.67*
1997	264.31	506.94	370.99	-2.27**
1999	543.39	836.59	673.70	-3.27***
2004	330.60	266.70	302.96	1.22
2009	860.61	903.52	877.97	-0.20
2014	1773.12	1062.06	1663.23	1.75*
Overall average	513.69	515.61	514.46	
Overall Std. Dev.	879.57	854.96	869.41	
Between Std. Dev.	707.70	526.74	649.63	
Within Std. Dev.	660.38	688.76	671.82	

Note: ***, ** and * refers 1%, 5% and 10% level of significance, respectively

Source: ERHS (1994a-2009) and own survey, 2014

The income collected from off-and non-farm activities showed significant difference in majority of the survey years (Table 19) for instance in 1997 and 2004. Smallholders in Arsi grain plough farming system collected better income from those activities in most of the survey years. The lower crop income in 1999 (Figure 6) may be the reason behind collecting better income from non- and off-farm activities. The income collected from off- and non-farm activities improved in central highlands farming system starting from 1997 that may be related with geographic proximity to big towns and the capital, which may create opportunities to have diversified sources wherein remote households could not access. Off-

and non-farm income exhibited relatively equal variation in the two farming systems, wherein the variation level between smallholders was relatively larger in central highlands.

4.1.6. Labor Displacement, Crop Income and Rainfall Variability

If there is no balancing between costs of departure and revenues obtained in the form of remittances, rural–urban migration could result in net loss for communities of origin that further constrain agriculture (Thomas, 2012). Mathilde and Zaneta (2014) confirmed that climate shocks lead to a higher probability of displacement through reducing agricultural yields, which in turn induced households to send their family away to spatially diversify their income sources. In 1999 about 47% of the migrant moved to other rural areas that are either within their district or outside, for instance 4% of them travelled to Addis Ababa. Given this, from the migrants in 1999, 2004 and 2009 about 50%, 28% and 25%, respectively were below 15 years old when they displaced, which implies that the rural economy is losing the younger generation. From the overall migrants between 1994a - 2014 more than 74% were less than 30 years, and majority (79%) of the displaced individuals were primary and junior school graduate, and below that level of education when they displaced. About 10%, 39% and 30%, respectively were basic literate, elementary and junior school graduate. Only 32% of the migrants were elementary school graduate in 1994a, but this percentage increased to 40% and 41% in 2004 and 2009, respectively. Similarly, 6% of the migrants in 1994a were junior school graduates and the percentage increased to 31% and 39% in 2004 and 2009 sample years, respectively.

The number of labor displaced from the two farming systems showed significant (p -value = 0.000) difference. Labor displacement possibility was very high for *kebeles* that have geographic proximity to the capital of the country as well as other secondary towns (Appendix table 15). Averagely 0.48 and 0.59 labors per household displaced from central highlands and Arsi grain plough farming system. Smallholders in central highlands and Arsi grain plough farming system collect average crop income of 1351.15 Birr and 1629.23 Birr on average, respectively. The better crop income in the latter farming system was not a guarantee for reducing the household members' movement. Thus, better crop income collection was not a guarantee to reduce rural labor displacement however, there should be further mathematical

test to have clear-cut conclusion whether there is positive or negative relationship between crop income and rural labor displacement.

Table 20. Yearly rural labor displacement from the two farming systems

Description	Labor displaced			Crop season rainfall	
	Central highland	Arsi grain plough	t-value	Central highland	Arsi grain plough
1994a	124	68	0.997	901	495
1994b	139	223	2.57***	872	712
1995	79	60	0.93	825	506
1997	165	101	2.65***	742	504
1999	121	38	0.84	893	652
2004	116	50	5.26***	822	523
2009	234	130	0.95	822	557
2014	108	48	4.25***	820	576
Total	947	495		832.14	544.71
Overall average	1.612	1.878			
Overall Std. Dev.	1.135	1.449			
Within Std. Dev.	0.835	1.069			
Between Std. Dev.	0.857	1.188			

Note: *** refers 10% level of significance

Source: ERHS (1994a-2009) and own survey, 2014

People in temperate zones have an even stronger focus on migration, and they are engaged in livelihood diversification and reforestation (Ole, 2011). This author argued that smallholders prioritize improvements and adaptation to agriculture both in case of a more humid and dry future climate, but in case of frequent droughts, displacement is the top priority. Rainfall variation from the long-run average level was one reason for movement of the rural labor from the two farming systems. Table 20 showed that crop season rainfall of the two farming systems was lower in 1997 that result in relatively higher rural labor displacement (266 people per annum) from the sample farming systems, and there was higher movement in that year than years before and after it. Similar circumstance happened in 2009 regarding cropping season rainfall and rural labor displacement from central highlands farming system. Continuous rainfall reduction could become a more important driver of rural–urban displacement flows (Mbow *et al.*, 2008). These all infer that there was strong interaction between number of rural labor displaced and rainfall condition of the two farming systems (Table 20). Thus, there is solid evidence to infer about negative relationship between rainfall

level and rural labor displacement from the two farming systems based on the above table, but it needs additional verification through the mathematical models (See section 4.5).

4.2. Effect of Climate Variability on Cereal Yield²

There are alternative models to regress panel data that enable to examine effect of climate variability on cereals' yield. The dependent variable was in physical quantity, yield, then explanatory variables should be also in quantity but not dummy type non-input variables. Elodie (2012) used four separate equations to estimate determinants of the four most commonly grown crops in SSA. In the same fashion, this research employed different equations to regress yield of *teff*, maize, wheat, barley and sorghum that are common cereals in the two farming systems. The coefficient of μ (mu) was significant for the time variant frontier model result of *teff*, wheat and barley (Table 21), which showed presences of time variant efficiency variability. The returns to scale of producing those cereals in the two farming systems were not in constant returns since the coefficient of μ was significantly different from zero. The relatively large value of μ for *teff* and wheat testified strong variability of the returns to scale for the two crops across time and individuals (Table 21).

The value of η (eta) in the following model result revealed significant production inefficiency reduction towards the base year, 2014. The inefficiency level decays towards the base year, since value of η (eta) is positive for the four cereals. The increment for maize was the highest compared to the other cereals, wherein *teff* had the lowest (Table 21). Stochastic frontier function of sorghum showed that the time invariant part of inefficiency variation was insignificant. Smallholders' production system of this crop had constant returns to scale, wherein there was no time variant inefficiency variation rather it had time invariant component only. The mean value of sorghum production inefficiency was not significantly different

² Part of this objective published on International Journal of Agricultural Management and Development (IJAMAD). "Impact of Climate Variability on Cool Weather Crops in Ethiopia: Panel Data Approach": Article on press: http://ijamad.iaurasht.ac.ir/article_527242.html

across individuals. The inefficiency for the other cereals had significant time variant component that was normally distributed with a constant mean and variance level.

Table 21. Time variant frontier model result

Input type	<i>Teff</i>	Wheat	Barley	Maize	Sorghum [♣]
ln Man equivalent	0.109** (0.045)	0.129*** (0.047)	0.105** (0.043)	0.020 (0.045)	0.174** (0.089)
ln Fertilizer	0.155*** (0.013)	0.098*** (0.012)	0.082*** (0.011)	0.158*** (0.013)	0.183*** (0.022)
ln Oxen	0.159*** (0.025)	0.050* (0.028)	0.027 (0.026)	-0.030 (0.024)	0.126*** (0.048)
ln Capital	0.024*** (0.007)	0.041*** (0.007)	0.028*** (0.007)	0.022*** (0.008)	0.017 (0.016)
ln Cropping season rainfall	0.760*** (0.087)	-0.124* (0.067)	0.332*** (0.108)	- 0.382*** (0.066)	-0.270 (0.281)
ln Cropping season temper.	-1.022*** (0.357)	0.984*** (0.214)	0.564*** (0.162)	-1.371*** (0.224)	-2.01* (1.044)
Constant	4.091*** (1.343)	3.576*** (0.846)	2.764*** (1.043)	12.872*** (0.805)	14.653 (41.475)
Mu (μ)	0.695*** (0.185)	0.901*** (0.191)	0.466*** (0.151)	0.008 (0.010)	0.769 (41.239)
Eta (η)	0.018*** (0.0034)	0.023*** (0.004)	0.056*** (0.011)	0.223*** (0.051)	-----
Ln sigma ²	-0.103 (0.083)	-0.161*** (0.044)	-0.637*** (0.037)	-0.407*** (0.037)	-0.489*** (0.070)
llgt gamma	-0.669** (0.260)	-0.919*** (0.154)	-2.774*** (0.317)	-9.596*** (2.038)	-3.058*** (1.160)
sigma ²	0.903	0.852	0.529	0.666	0.613
gamma	0.336	0.285	0.059	0.0001	0.045
sigma_u ²	0.306	0.243	0.031	0.0001	0.028
sigma_v ²	0.597	0.609	0.498	0.666	0.586
Log likelihood	-2616.5	-2870.6	-2089.6	-2080.2	-486.7
P-value	0.000	0.000	0.000	0.000	0.000

Note: ***, ** and * implies 1%, 5% and 10% level of significance, respectively

ln represents natural logarithm

♣ Time invariant frontier model output

llgt implies inverse logit

Source: Model result, 2016

Inorganic fertilizer had significant and positive effect on yield as to the model result, which means small unit increment in its application could enhance yield significantly. Sibiko *et al.* (2013) showed that plot-size, seeds and planting fertilizer usage significantly influenced bean productivity. Any fertilizer usage increment could enhance wheat, maize, barley and sorghum

productivity (Ajay and Pritee, 2013), which was a finding corroborated with the above model result for all cereal crops. The model result in Table 21 shows that inorganic fertilizer and working capital had significant and positive effect on cereals' yield for smallholders in both central highlands and Arsi grain plough farming systems of Ethiopia. Rahman and Umar (2009) and Ehsan *et al.* (2012) also claimed that there is positive relationship between wheat yield and fertilizer application, which was in support of the model result in Table 21. Increasing the available capital for purchasing inputs like seed, pesticides and insecticides resulted in significant cereal yield increment as to the model result.

Oxen power and human labor had similar effect on cereals yield in the study area. Their complement behaviors may be the reason behind having similar interaction between the two sources of power and cereals yield in the two farming systems. Cereals are laborious crops and smallholders in the two farming systems manage them by human and animal power starting from plowing to harvesting, thus each change in the available labor had significant effect on yield. Smallholders' crop yield variation may not purely climate forcing that is determined solely by rainfall, but also by the use of yield-improving external inputs (Amikuzuno and Donkoh, 2012). Similarly, Akinseye *et al.* (2013) confirmed that optimum yield performance of any crop do not depend only on climatic parameters. Smallholder farmers in less drought-stricken regions may improve land productivity through budgeting more labor and other production inputs (James *et al.*, 2008), which was a finding similar to Table 21 regarding effect of human labor and draught power. Since smallholders of the study area are purely dependent on animal and human power for producing their crop, this positive and significant effect of the inputs on cereal yield was expected.

The two dominant climate variability elements (cropping season rainfall and temperature) significantly affected cereal yield in central highlands and Arsi grain plough farming system of Ethiopia. Cropping season temperature increment had positive and significant effect on yield of wheat and barley as to the model result (Table 21). This indicated that temperature variation significantly changed yield of the two crops. If cropping season temperature of the area increased by 1%, yield of wheat and barley would increase by 0.98% and 0.56%, respectively, wherein the former crop was more sensitive for each temperature variation. This

finding was similar to Joshi *et al.* (2011), wherein cropping season maximum temperature increment has positive contribution on wheat and barley yield variation. Wheat and barley are cool weather crops produced in *dega* and *woina-dega* agro-ecologies of Ethiopia, then temperature increment may create propitious environment to improve yield. This finding had partial similarity with Govinda (2013), who argued that wheat yield increased while barley decreased with seasonal mean temperature increment. Similarly, Sommer *et al.* (2012) found that wheat yield would increase in the future with the projected climate change in the semiarid zone of Tajikistan.

The result in Table 21 was in contradiction with Geethalakshmi *et al.* (2011), who identified that mean temperature increment reduced barley yield. Liangzhi *et al.* (2009) argued that impact of growing season temperature on wheat productivity is region specific, wherein effect of the problem is relatively lower in China as compared to the other regions. Successive temperature increment would not affect crop yield if there were extensive rainfall or water supply to curve down the moisture loss of crops (Kutcher *et al.*, 2010). This indicated that positive interaction between cropping season temperature and yield of those cereals might be due to the excessive cropping season rainfall of the study area. The rampant rainfall of *dega* and *woina-dega* agro-ecology of Ethiopia may reduce negative effect of the temperature rise. In the other direction, successive temperature increment may eradicate waterlogging problem of the heavy summer rainfall and enhance wheat and barley yield. Thus, it may be easy to conclude that yield of the two cool weather crops would increase due to continuous cropping season temperature increment.

As climatic conditions vary, production patterns of different crops could change differently (Aye and Ater, 2012). Different crops have different optimal level of temperature and precipitation, and movement away from that may be destructive, especially in areas where the current temperature and precipitation levels are already close to tolerance limit of the crop. Cropping season temperature rise would significantly decreased yield of *teff*, maize and sorghum in the study area (Table 21). Maize and Sorghum yield would improve significantly for each unit reduction in drought level (Inoussa, 2010), which was a finding that verified the current result in Table 21. This finding was in support of Pratap *et al.* (2014) in which an

increase in maximum temperature adversely affected the crop yield in India. The model result in Table 21 revealed that sorghum yield was most sensitive (2.01%) followed by maize (1.37%) for 1% increment in cropping season temperature.

Rainfall within the suitable range had positive effect on crop yield, but successive increment, *ceteris paribus*; exert downward shocks (Amikuzuno and Donkoh, 2012). The model result in Table 21 also shows that cropping season rainfall had positive and significant effect on yield of *teff*, barley and sorghum. Pratap *et al.* (2014) found that rainfall increment had positive effect on yield, but the effect was not strong enough to counterbalance negative effect of temperature. Those crops produced in *kola* and *woin-dega* agro-ecologies of Ethiopia wherein cropping season rainfall increment may significantly increase yield. The current time rainfall of the area may be around optimum level, then its increment would directly improve yield of sorghum, barley and *teff* in the two farming systems of Ethiopia. Fantu *et al.* (2011) identified that crop production in Ethiopia is sensitive to rainfall variation, which was a finding in support of the current one (Table 21). Based on the model result yield of sorghum and *teff* would increase by 0.27% and 0.76%, respectively, for a 1% increment in cropping season rainfall. Further increment of the covariate from the current level may result in 0.12% and 0.38% yield reduction for wheat and maize, respectively, in the two farming systems as to the model result. This finding had similarity with Tajudeen and Michael (2011) who argued that subsequent increment in growing season rainfall would decrease maize production. Yield of wheat and maize would significantly decrease if the cropping season rainfall continuously increases. In general, yield variation effect of change in cropping season temperature was stronger as compared to the rainfall (Table 21).

Estimation result of technical efficiency (TE)³:

Average TE of cereals in the two farming systems had significant difference (Appendix Table 12), wherein smallholders in central highlands had lower TE. Households in Arsi grain plough were better in producing the potential output from the given combination of inputs at the existing technology level. Households in the two farming systems were most inefficient in producing wheat followed by *teff*, wherein they had unutilized potential of 61.50% and 54.10% for the two crops, respectively. Households in the two farming systems could increase

³ To avoid complications for readers the dependent variable was technical efficiency but not inefficiency

teff and wheat yield by more than 50% from the given inputs at the existing technology. As compared to the other cereals smallholders had better TE in producing maize (83.0%) followed by sorghum (57.60%).

GLS random effect regression was adopted due to its efficiency and robustness in controlling heteroscedasticity problem, and the dependent variable in the model was between 0 and 1, calculated from the stochastic frontier model. All of the independent variables were different from zero and had partial contribution in the TE variation for the five cereals in the study area. The p-value enables to reject the null hypothesis with high confidence level assuring that at least one of the covariates had significant effect on the dependent variable. The TE scores computed from frontier model result were between 0 and 1 but not equal to either of the two boundaries for the five cereals. This revealed that none of the sample smallholders was either at the frontier level or producing 0 from the given input combination. The whole sample households were technically inefficient in producing sample cereals, which result in having TE scores that lie between 0 and 1. Since there were not censored observations, the study rejecting *Tobit* model instead the best alternative model for linear type of observation GLS was employed.

The regression result presented in Table 22 considered three broadly categorized types of explanatory variables that affect smallholders' TE in producing cereal crops. Wheat and barley responded similarly for variation in some of the covariates considered as an explanatory. Timely onset of summer rainfall in the two farming systems significantly increased smallholders' TE of producing barley, maize and sorghum, which was in support with Inoussa, (2010) who claimed that precipitation intensity affected sorghum yield significantly. Consistent availability of rainfall starting from the beginning may create auspicious environment for producing those crops efficiently. The long seasoned cereals, sorghum and maize, may seriously demand the rainfall at the beginning of summer season to have better yield. The circumstance may be true for barley, which has similar sowing time with those cereals though it is a short seasoned type. The adequate rainfall at the beginning of summer may enable smallholders to sow cereals on time, which would enhance their TE in producing long seasoned crops such as maize and sorghum.

TE of smallholders in producing cereals responded similarly to harvesting season rainfall. Frequent happening of this problem in harvesting season could result in serious yield variability that might decrease smallholders' TE as to the model result (Table 22). The five major cereal crops were strongly responsive to this problem wherein barley and wheat are more sensitive. Smallholders' TE in producing barley, wheat and maize, respectively, decreased by 17.8%, 14.2% and 9.6% if there was harvesting season rainfall. The coefficients indicated that barley and wheat production were more sensitive to one of the dimensions for climate variability, harvesting season rainfall. Even if the coefficients were not strong like the previous cereals, but occurrence of the problem had significant effect on TE of households in producing sorghum and teff.

Table 22. Determinants of TE, GLS regression result

Variables description		<i>Teff</i>	Wheat	Barley	Maize	Sorghum
Climate variability	Summer rain on time	0.001 (0.006)	0.004 (0.008)	0.159*** (0.0119)	0.086*** (0.009)	0.042*** (0.012)
	Harvesting time rain	- 0.046*** (0.007)	-0.142*** (0.008)	-0.178*** (0.012)	-0.096*** (0.006)	-0.047*** (0.012)
	Pests	0.007 (0.008)	-0.090*** (0.009)	-0.123*** (0.015)	- 0.021** (0.011)	-0.159*** (0.016)
	Climate sourced Shocks	0.006 (0.007)	-0.050*** (0.007)	0.0098 (0.012)	-0.003 (0.007)	-0.0004 (0.012)
Demograph	ln Family size	-0.044*** (0.007)	0.029*** (0.008)	-0.081*** (0.012)	-0.097*** (0.005)	0.161*** (0.012)
	ln Age of head	0.124*** (0.009)	0.051*** (0.011)	0.061*** (0.016)	0.099*** (0.008)	0.036* (0.019)
Economic	ln Livestock holding	0.057*** (0.004)	-0.009*** (0.003)	0.033*** (0.008)	0.036*** (0.004)	-0.008* (0.004)
	Credit access	-0.035*** (0.006)	0.036*** (0.008)	0.095*** (0.012)	-0.036*** (0.007)	-0.072*** (0.012)
	Off –farm income	-0.022*** (0.005)	-0.034*** (0.006)	-0.040** (0.014)	-0.012* (0.006)	-0.031** (0.012)
Constant		-1.257*** (0.041)	-0.878*** (0.053)	-0.640*** (0.080)	-0.116*** (0.040)	-0.586*** (0.009)
P-value		0.000	0.000	0.000	0.000	0.000

Note: The dependent variable was TE in percentage

The coefficients showed changes across time and household level
Source: Model result, 2017

Climate change will reduce crop productivity up to 14% by 2020 (Srivastava *et al.*, 2010), and yields are likely to be affected even more in 2050 and 2080, which was a finding highly related to Table 22. Outbreak of pests and diseases significantly decreased TE of households in the study area for producing the four cereals, wherein sorghum and barley were more sensitive (Table 22). In identifying impacts of current climate variability, Kettlewell *et al.* (1999) showed that heavy rainfall could result in fungal disease outbreak that would finally reduce yield.

The demographic related factors including age of the household head had similar effects on smallholders' TE of producing the five cereals. Experienced household heads would have significant effect on TE of smallholders in the two farming systems in producing cereals. Having experienced household head would significantly increase TE of households in producing the two crops, which was a finding in support of Hardwick (2009), Zenebe *et al.* (2012) and Sibiko *et al.* (2013). One of the critical crop production input, human labor, may be easily available if the household had larger family size, which would improve TE of producing cereals. Family size increment may be a source of labor power for the crop production that would enhance TE of wheat and sorghum, which was a finding corroborated with Rahman and Umar (2009). Family size increment has both productive and consumption effect, wherein TE of households in producing cereals would be depending on magnitude of the two effects. The latter effect may be the reason for having negative effect of the covariate on TE of producing *teff*, barley and maize in the study area. Similarly, age of the household head had significant effect of increasing the TE of *teff* and sorghum.

Given those covariates, the study also considered other economic factors as an explanatory variable that have significant effect on smallholders' TE in producing cereals. Household's TE of producing *teff*, barley and maize responded similarly to the livestock holding level. Farmers with more livestock units, which are ready to convert into cash, can be able to buy modern inputs than those that own fewer (Fantu *et al.*, 2011). Possession of large livestock could significantly increase TE, which may be due to having additional income

and labor for the crop production (Table 22). Participation of households in off/non-farm activities had negative and significant effect on TE of producing cereals in central highlands and Arsi grain plough farming systems of Ethiopia, which may be due to labor competition between the crop production and those activities.

4.3. Climate Variability and Smallholders' Crop Income

Crop production variability due to weather variation would finally result in high net income volatility from the sub-sector (Susanne, 20012). This implies that climate variability has strong effect on smallholders' income if crop production is the main source. This research assumed that climate variability has no fixed effect like demographic and idiosyncratic shocks on smallholder's crop income. Once the correlation with individual effects was modeled through an auxiliary regression, random effects specification provides consistent estimators in estimating time invariant variables (Debarsy, 2012). The choice between fixed and random effect approach of estimating the panel data dependence on different circumstances like the method of data collection, type of population from which samples were drawn and purpose of the analysis (Franco, 2001). Franco (2001) also argued that if the interest of a research is to examine specific difference among small number of entities, it is better to use fixed effect model of regressing the panel data. The main interest of this research was to investigate effect of the time variant climate variability elements on households' crop income. The time invariant household related dummy variables were not main concern of the study. This intention demands utilization of fixed effect model regression. Given those, ordinary means of identifying method of regressing, this research conducted the required diagnostic tests to identify the appropriate model of analyzing the unbalanced panel data.

Table 23. Breusch and Pagan LM test

Type of variable	Coefficient	Standard error	P-value
ln Crop income	7.264	2.695	0.000
e	4.600	2.144	
u	1.090	1.044	

Note: ln represents natural logarithm

Source: Regression result, 2017

The test result (P-value =0.000) in Table 23 showed that there was significant evidence to accept random effect model of regression. After rejecting pooled OLS via the Breusch and Pagan test, the research just proceed to the next test to identify between random and fixed effect, and to do so this study did Hausman specification test. Based on the p-value in Table 24 the null hypothesis, “the time invariant individual related dummy covariates are uncorrelated with other regressors”, was rejected, which assured selection of fixed effect model of regressing the unbalanced panel data. As to the test result presented on Table 24 the null hypothesis has been rejected.

Table 24. Hausman test result for fixed and random effect model selection

Variable	Coefficient		Difference (FE- RE)	sqrt(diag(V_FE-V_RE)) stan.err.
	Fixed (FE)	Random(RE)		
ln Rain	32.914	-4.873	37.787	3.560
ln Temperature	85.612	-1.787	87.399	8.695
ln Rain X T ^o	-10.731	1.365	-12.095	1.138
Harvesttime rain	-0.518	-0.533	0.016	0.018
Growing time rain	0.748	0.891	-0.143	0.018
Summer rain onset	0.308	0.227	0.081	0.015
(Fe-RE)'[(V_FE-V_RE) ^ (-1)](FE-RE) = $\chi^2(6)$		P-value	0.000 accept fixed effect	

Note: ln represents natural logarithm

Source: Regression result, 2017

The model selection test in Table 24 considered climate variability elements as an explanatory, and the test result verified to accept fixed effect model of regression. The test result verified that time invariant household related dummy covariates correlated with the others and there was no difference in households' income as of those variables.

The F-value in Table 25 shows none of the independent variables was zero; rather each one has its own contribution in explaining the variation in the dependent variable. Given this, more than 32.91% (Rho value = fraction of variance due to μ_i) of the variation in the dependent variable was due to panel effect (Table 25). The model result revealed that rainfall and temperature increment affected smallholders' crop income significantly and negatively as well. Interaction of crop income between the two dominant climate variability elements (rainfall and temperature) was negative for sample households in the two farming system of

Ethiopia. This negative effect of the two covariates indicated that partial effect of either rainfall or temperature was negative, which was a finding similar to Félix and Romuald (2014), who argued that changing rainfall pattern is a source of uncertainty and agricultural income fluctuation. Those authors argued that rainfall variability had negative effect on agricultural income of developing countries that depend on rain-fed crop production. Contrary to the result on Table 25, Ajay and Pritee (2013) identified positive and statistically significant effect of rainfall on agricultural produce value. Their finding implied that rainfall increment is beneficial for increasing production value due to lower quantity produced, and finally improve income. This positive effect of climate variability on households' income could not be acceptable for Ethiopian smallholders who have not marketable amount to collect benefit of crop price increment. A 1% increment in cropping season temperature or rainfall, respectively, resulted in 10.51% and 8.32% crop income reduction for a given household. The covariate generated based on interaction of rainfall and temperature had positive and significant effect on smallholders' crop income. Thus, climate variability had negative effect on smallholders' crop income, which may be due to its strong effect on the marketable amount.

Other variables such as climate-sourced shocks affected smallholders' crop income negatively. Occurrence of them would have a devastating effect on crop production that may result in complete loss of produces. Covariates related to rainfall inconsistency such as timely onset of summer rainfall and enough rain at sowing time significantly affected smallholders' crop income. Availability of sufficient rainfall at the beginning, and consistent supply throughout crop growing season may increase the marketable amount of crops through improving the quantity produced. Earlier works conducted in Africa were in support of the result presented on Table 25, for instance Ole (2011) found that rain-fed agriculture income reduction largely attributed to insufficient (quantity and distribution) of rainfall in many west African countries. Kaul and Ram (2009) argued that excessive rain and extreme temperature variation adversely affected crop productivity and thereby influence income of farming families. Some extreme events are associated with very poor harvests of cash crops, which severely affect income of the farming sector (Marc *et al.*, 2013).

The other variable sourced from temperature and rainfall inconsistency was pest infestation, which strongly affected crop income (0.15% reduction). Pest commonly known as *faki* highly affect crop production of households in central highlands and crops planted in areas infested with this pest produce nothing (Dercon and Hoddinott, 2011). Drought was main causal factor triggering poverty through changing the crop production (Yue *et al.*, 2013). Smallholders across the tropics already faced numerous risks including pest and disease outbreaks, extreme weather events and market shocks that frequently reduced household agricultural production and income (Celia *et al.*, 2014).

Table25.Effect of climate variability on crop income

Description	Coefficients	Robust Standard error
lnRainfall	-8.323***	1.014
lnTemperature	-10.514***	1.211
lnRain X Temperature	2.466***	0.302
Climate sourced shocks	-0.243***	0.066
Idiosyncratic shocks	-0.173***	0.065
lnLivestock holding	0.342**	0.150
Pests	-0.154*	0.082
Rain at harvest time	-0.145**	0.072
Enough rain at beginning	0.589***	0.080
Summer rain on time	-0.038	0.069
Off/non-farm activities	-0.309***	0.068
Access to credit	0.583***	0.083
Crop residue	1.253***	0.097
lnHousehold size	-0.580***	0.114
lnNumber of oxen	0.343***	0.073
lnCropland	0.191***	0.032
Constant	42.236***	4.115
Sigma_u	1.360	Prob > F 0.000
Sigma_e	1.942	Corr(u_i, Xb) 0.0746
Rho(ρ)	0.329 (fraction of variance due to u_i)	
R ² -within	0.235	
R ² -between	0.439	
R ² -overall	0.313	

Note: ***, ** and * refers 1%, 5% and 10% level of significance, respectively

ln represents natural logarithm

The variation in panel data is two-dimensional (Across time and household)

Source: Regression result, 2017

Agricultural labor and mechanization negatively affect the value of production in India (Ajay and Pritee, 2013) since there would be excess production but the overall crop income effect is positive through increasing marketable amount. Similarly, draught power allocated for agriculture, which are critical inputs in Ethiopian smallholder crop production, had positive and significant effect on crop income as to the model result (Table 25). For a given smallholder 1% increment in the draught power would increase the crop income by 0.34%. Household member's participation in off/non-farm income had negative and significant effect on crop income, which was a finding similar to Tesfaye *et al.* (2015) each additional earning from off/non-farm activities has negative and statistically significant effect on marketed surplus. The negative effect of off/non-farm income may be due to labor competition between crop production and other activities that would result in crop produce reduction. Having easy access to saving and credit facilities had significant and positive effect on crop income collection of households in the study area. Capacity of smallholders to purchase agricultural inputs could be easy if they have access to credit, which could enhance production and marketable amount.

The large family size in rural Nigeria consumed all the produced that would result in lower household income, little savings, and increased poverty (Omideyi, 1988). Similarly, Tessema (2015) argued that the number of dependency ratio significantly reduced rural household's income. Smallholders' family size has two contradictory effects on crop income: the consumption effect that reduced crop income due to large home consumption of the marketable produces. Additionally, family size has production effect that increases crop income through excess supply of marketable amount. Thus, overall effect of family size increment always depends on magnitude of the two effects within the household. Based on Table 25 the variable had negative effect on crop income collection, which means the consumption effect outweighs production. Negative interaction of family size and crop income implied that large family size might have more of consumption effect but not production for smallholders in the two farming systems of Ethiopia. The marketable amount that directly increased crop income could increase if a household had small family size. The

reduction in household's consumption could shift produces to be marketable type, which guaranteed better crop income.

4.4. Determinants of Adaptation Strategies to Climate Variability⁴

Smallholders in the two farming systems of Ethiopia took different measures to curve negative effect of climate variability. They provided attention for cropping season rainfall variation and inconsistency for selecting adaptation strategies. This research grouped the different alternative strategies into four categories based on similarity in making decision about adopting each one and type of benefits to be collected (See section 3.4.3). Since smallholders' adaptation strategies in the study area were mutually inclusive, separate uni-variate probit regression could not provide reliable result about determinants of alternative strategies. Multivariate probit (MVP) specification allowed systematic correlations among the different alternative strategies, and identified specific drivers of each type of adaptation strategies. This approach considered the potential interdependence among alternatives and possible correlations of the error terms due to unobservable characteristics that influence adoption of strategies (Chib and Greenberg, 1998). Strategies may be complementary if the equations defining them are significantly and positively associated among themselves (Cassiman and Veugelers, 2006).

As to the simulated maximum likelihood MVP model result in Table 26, some of the sample smallholders in the study area employed combination of more than one adaptation strategy to curve down the negative effect of climate variability. In this case, the probability of choosing a particular adaptation strategy is conditional on the probability of choosing any other. ρ_{ij} (Rho), the correlation coefficient between the residuals of strategies, was significantly different from zero (Table 26) indicating that the MVP model was more appropriate than separate uni-variate probits or multinomial probit. The null hypothesis of $\rho_{12} = \rho_{13} = \dots = \rho_{ij} = 0$ could be rejected at 1% significant level having p-value = 0.000, which implies that alternative strategies are mutually inclusive. The test showed presence of interdependence

❖ ⁴Presented on a national conference titled "Agriculture, Climate Change & Environmental Safety: The challenges on National Transformation in Ethiopia". Organized by Wollega University, Shambu Campus, Shambu, Ethiopia.

among alternative strategies. Households may consider different adaptation choices simultaneously since there may be complementarities among alternatives.

Table 26 showed that the joint probability of success was 12.04%, which revealed probability of adopting all the strategies at a time. Joint probability of failure to adopt all the strategies at a time was 5.85%, which was the probability that households of the area failed to adopt all the strategies at a time. Strategies related to agricultural technology adoption (Strategy 2) had relatively larger marginal probability of success (65%) followed by changing the crop sowing time (Strategy 1) (62%). The average standard errors of prediction for each equation in the MVP were 0.26, 0.33, 0.27 and 0.32. At the same time, average linear predictions of each equation 1, 2, 3 and 4, respectively were 45.2%, 73.5%, 21.2% and 25.5%. There was strong correlation between error terms of strategy 1 and 2, strategy 2 and 4, and strategy 3 and 4 (Table 26), which indicates that MVP model was the right methodology to regress the data.

Some of the variables such as distance from the main road, previous year cropping season rainfall shortage and crop price were common factors that affected the four alternative strategies significantly. The first variable had negative effect on adopting strategy 1 and 3, while it affected long lasting strategies (2 and 4) positively. If a household is in short distant from the main road, then probability of adopting strategies 1 and 3 increases significantly. Access to alternative source of income and information about those strategies would be easy if the household is in short distance from the road. Households may not have easy access to infrastructure facilities to make them telepathic about recent issues unless they are in short-distance from the road. To have successful adaptation planning proper institutional structures should be in place to deliver climate-proofed development programs that result in the necessary behavioral and structural changes (Arjanet *al.*, 2011). Households at long distance from the main road would significantly be initiated to adopt strategy 2 and 4 (Table 26). This indicated that dwelling in long distance from accessing infrastructures like road and market as well as new sources of information may lead smallholders to employ long-lasting strategies that improve their agricultural production. Adoption of new technologies like hybrid crop varieties, modern inputs, reforestation, water harvesting and others could get due attention if households dwell at distance location from the main road.

Table 26. Determinants of household's adaptation strategies

Variables	¹ Changing sowing time		² Technology adoption		³ Alternative income		⁴ Conservation	
	Coefficient	Std.Error	Coefficient	Std.Error	Coefficient	Std. Error	Coefficient	Std.Error
Shocks	-0.069	0.185	0.488**	0.205	0.601***	0.192	0.042	0.220
Pests	0.219	0.172	-1.070***	0.242	0.683***	0.197	-1.070***	0.229
Expected drought	0.953***	0.219	0.761***	0.241	0.279	0.241	0.943***	0.271
Rain at harvest seas.	0.299	0.161	0.534***	0.194	0.205	0.161	0.706***	0.188
Prev. rain shortage	0.635***	0.191	-0.429**	0.217	0.608***	0.204	-0.754***	0.240
Distance from road	-0.014***	0.004	0.025***	0.010	-0.015***	0.005	0.016***	0.006
Food requirement	-0.677***	0.170	0.611***	0.187	-0.133	0.179	0.509**	0.197
Crop price	0.337**	0.168	0.493***	0.180	0.285*	0.175	0.703***	0.198
Crop income	-0.001	7.5e-04	0.003**	0.001	-5.3e-05	8.1e-05	0.002*	8.4e-05
Save account	----	-----	0.166	0.192	0.651***	0.185	-0.319	0.199
Loan	0.451***	0.157	----	-----	0.701***	0.180	-0.139	0.205
Electric	-0.276	0.256	0.449	0.292	-0.444**	0.208	0.900***	0.325
Agricultural labor	-0.067	0.049	0.091*	0.052	----	-----	-0.047	0.054
Pipe water	-0.261	0.239	0.435	0.285	----	-----	1.725***	0.323
Constant	-0.270	0.661	-0.824	0.826	-2.974***	0.429	-2.459***	0.860
Rho(P ₂₁)	-0.466***	0.111			Joint probability success			12.04%
Rho(P ₃₁)	0.078	0.106			Joint probability failure			5.85%
Rho(P ₄₁)	0.030	0.123			Likelihood ratio Rho _{ij} =0 P> χ^2			0.000
Rho(P ₃₂)	-0.060	0.121			Log likelihood			-678.98
Rho(P ₄₂)	0.350***	0.108			Number of observations			575
Rho(P ₄₃)	-0.314***	0.117						
Marginal Prob. of success	62%		65%		43%		55%	
Standard errors prediction	0.26		0.33		0.27		0.32	
Number of adopters	356		374		247		316	

Note: ***, ** and * represent 1%, 5% and 10% level significance, respectively

The alternative strategies named Strategy_1, _2, _3 and _4 to simplify the discussion

Strategy_1 and _3 were short- run strategies, Strategy_2 and _4 were long-lasting strategies

Due to manageability problem, the off-diagonal values of the error covariance matrix (atrho_{ij}) were not included in the table

Source: Model result, 2016

Frequent occurrence of cropping season rainfall shortage within the previous five production years had significant effect on adopting all the strategies commonly. The covariate had positive and negative effect on adopting strategy 1 and 3, and the long lasting strategies (2 and 4), respectively. Positive and significant effect of the parameter on adopting strategy 1 implies that smallholders would be active enough in changing the sowing time if there were consecutive rainfall shortage in the previous successive five production years. Positive interaction of cropping season rainfall shortage and strategy 3 indicated that smallholders of the two farming systems sought to change their economic dependency to other means of survival like adopting off- and non-farm activities to supplement their agriculture-sourced income. Smallholders' capacity to adapt climate change is perhaps the most vital area for development (Stephen, 2009) and that may need support from institutions. Smallholders may look for alternative sources of income if they faced successive cropping season rainfall shortages for their crop production. The problem would not initiate households to adopt long lasting strategies (2 and 4) including new technology adoption; planting different varieties, irrigation and other activities that require relatively larger working capital. Some adaptation options are characterized as: too costly, resource intensive or cost ineffective until climate change effects grow to merit investment costs (IPCC, 2014b). This argument of the institution holds true for smallholders in the two farming systems of Ethiopia regarding the effect of rainfall shortage on adopting the long lasting strategies.

Based on the model result smallholders would prefer strategies that do not need large working capital to implement in order to cope up with problems of climate variability. Many of the adaptation strategies had positive expected net benefits but smallholders frequently faced financial constraints (Arjanet *al.*, 2011) in managing those strategies that are costly and require higher skills. This circumstance could be strengthened for households in the study area based on relationship of crop price improvement and the alternative adaptation strategies (Table 26). Smallholders' adaptation actions are very sensitive to both climate change and output prices (Robert, 2009), which was a finding that corroborate with the above table regarding relationship of crop price improvement and alternative strategies. Adoption of agricultural technologies requires sufficient financial wellbeing (Knowler and Bradshaw, 2007). Similarly, Table 26 revealed that getting better crop price had positive and significant

effect on adopting strategies that need relatively large working capital to manage. This logic may be one direction in having positive and significant relationship between crop income and adoption of strategy 2 and 4 (Table 26). Implementation of the long lasting strategies required relatively large investment and there should be collection of better crop income to do that. The poor, who often are budget constrained, are less likely to practice adaptations to climate change that require relatively larger investments (Agarwal, 2010; Vermeulen *et al.*, 2011). Crop price increment also initiated smallholders to adopt short-run strategies (1 and 3). Collecting better crop income may be a guarantee to implement strategies like non- and off-farm activities that generate additional income. Crop price improvement would result in crop income increment that guaranteed smallholders to have enough working capital for adopting new technologies that need large working capital.

Given the above covariates, others like drought expectation, household food requirement, and outbreak of pests and diseases had significant effect on adopting three of the alternative adaptation strategies. If smallholders faced outbreak of pests and disease that may be sourced from climate variability, then there would be significant initiation to adopt strategy 3 that are alternative source of income. Outbreak of this problem may result in adoption behavior shifting from strategy 2 and 4 to 3, which was a strategy that generate additional income. Occurrence of shocks that resulted in devastating effect on crop production and income significantly initiate smallholders to look for additional sources of income. If households expected drought in the coming crop season, then they would take an immediate measures such as changing sowing time, type and variety of crops to compensate expected production lose. This problem initiated households to employ a combination of two or more strategies in one production season. Significant and positive interaction of adopting those strategies and expecting future drought revealed that smallholders of the two farming systems had the awareness about the climate variability though they were not clairvoyant to respond perfectly as to the circumstance. Smallholders may be initiated more to apply two or more strategies at a time to curve effect of rainfall and temperature variability, which are common problems for households in central highlands and Arsi grain plough farming systems of Ethiopia.

4.5. Climate Variability as Driver of Rural Labor Displacement⁵

The initial assumption of this research, crop income variation is main source of rural labor displacement, had an implication of creating endogeneity problem in modeling the dependent variables (See section 3.4.4). Mathematical formulation of rural labor displacement indicated presence of strong endogeneity problem due to incorporating crop income as one explanatory covariate while its variation explained by others. The test result after instrumental regression indicated that there was strong endogeneity problem in the mathematical formulation. Both Durbin χ^2 score and Wu-Hausman F-value test results revealed rejection of the null hypothesis that was “*variables are exogenous*” with strong evidence ($p = 0.011$). The endogenous model should pass over the other three tests that are under identification, over identification and weak instrument test. The first problem had null hypothesis “*matrix of reduced form coefficients has rank = $K-1$ (under identified)*”, which was rejected by both Anderson canon and Cragg-Donald tests having significant level of P-value = 0.000. Cragg-Donald F-value of 12.73 was greater than the tabulated value of Stock-Yogo weak identification test’s critical value that was 11.39 (Appendix Table 13). These two values showed that the null hypothesis (H_0 : *equation is weakly identified*) rejected at 10% significant level.

The tests for joint significance of endogenous regressors’ coefficient $B_i = 0$ in the main regression equation that was one indicator of over identification was rejected at 1% significant level since Anderson canon correlation likely ratio statistic had value of 403.51 and P-value of 0.000. This test indicated that the endogenous variable had non-negative coefficient in the mathematical formulation. Additionally, Sargan-Hansen statistics that is the best test to examine over identification problem had a value of 48.03 and P-value = 0.004, which was significant enough to reject the null hypothesis at 1% level of significance. The endogeneity problem was the core issue behind manipulation of instrumented random effect two stage least squares (2SLS) regression. Table 27 showed two model results together in which the

⁵It was presented in 14th international conference on Ethiopian economy prepared by Ethiopian Economics Association: July 21-23, 2016.

The article published on 14th proceeding of international conference on Ethiopian Economy

first stage generated the predicted value of the endogenous variable, crop income, to be considered in the second stage regression as an explanatory. The under and over identification problem of the model limit the number of instrument variables in the first stage and core variables in the second stage of 2SLS regression. The model that considers the following instrument and core variables (Table 27) fulfilled all model diagnostic tests presented above.

Collecting better crop income would significantly reduce the proportion of displaced household member. Thereby the main covariate, crop income, in the model had the expected direction of relationship with the dependent variable, ratio of displaced labor to family size. Mathilde and Zaneta (2014) argued that migration decision determined by agricultural income and 1% reduction in it induced by weather shock increases the probability of migration by 3%. Similar circumstance happened in the two farming systems of Ethiopia as to the instrumented random effect 2SLS model result in Table 27, wherein expected crop income variation had significant effect in changing the rural labor displacement. A 1% expected crop income increment would reduce proportion of household member who displaced by 2.6%. This negative and significant effect of the covariate on labor displacement from the two farming systems indicated that climate related factors, which affect crop income would have induced effect on labor displacement. All the climate variability elements that negatively affect smallholders' crop income would aggravate displacement of the family member from sample households in the two farming systems.

The model result revealed that productive resources like TLU, a parameter of measuring rural household's wealth as well as source of labor, food and cash had significant effect in reducing family member displacement from the two farming systems. A 1% increment in TLU of a household would reduce the proportion of family member who displaced by 4.5%. Livestock holding of smallholders in Ethiopia mainly considered as a measure of social status and sometimes it can be an insurance premium. Thus, household members may feel insured when they do have large TLU in which the circumstance may reduce the labor displacement. Similarly, draught power increment could significantly reduce rural labor displacement from central highlands and Arsi grain plough farming system of Ethiopia as to the model result (Table 27). Since crop production of smallholders in Ethiopia is purely depend on animal

draught power for the whole process starting from soil preparation to harvesting time a 1% increment in the number of oxen could reduce the labor displacement by 15%, which was strongest compared to any of the covariates considered. Given this, rent income from oxen power may be thereas an additional income source for the household to create stability of the family member.

Table 27. Instrumental random effect 2SLS regression result

Second stage regression result			
Variables		Coefficient	St. Error
ln Crop income (Predicted value)		-0.025*	0.014
ln TLU		-0.044*	0.026
ln Draught power		-0.152***	0.027
Off/non-farm participation		-0.071**	0.036
ln Land labor ratio		0.096***	0.014
Crop residue collection		-0.018	0.050
Education		-0.162***	0.035
ln Age		-0.059	0.060
ln Inflation		0.008	0.031
Save account		-0.026	0.041
Idiosyncratic shocks		0.034	0.034
Constant		1.220***	0.248
Rho (variance due to u_i)	0.301	R ² _within	0.070
sigma_u	0.341	R ² _Between	0.1284
sigma_e	0.519	R ² _Overall	0.1092
First stage regression result			
ln crop season rainfall		-0.736***	0.234
ln crop season temperature		3.831***	0.417
Outbreak of pests		-0.413*	0.218
Enough rain at the beginning		0.239	0.202
On time summer rainfall		-0.230	0.204
Climate related shocks		-0.359**	0.162
Harvest time rainfall		0.151	0.176

Note: ***, ** and* represent 1%, 5% and 10% level significance, respectively.

ln represents natural logarithm

Source: Model result, 2016

Table 27 also disclosed that if any of the household members participated in off-farm activities, then displacement of labor would significantly diminished. Relatively diversified income to fulfill their consumption demand would guarantee household members to stay in

rural areas and look for other alternative livelihood strategies around their permanent place. If the household had diversified income sources, then family members may prefer to stay on their agriculture rather than moving to other places. Off-farm income, crop residue collection and access to saving had negative interaction with rural labor displacement from the two farming systems. This implies that the crop income, households currently collect, is not enough and guarantees them to stay in their dwelling places. Thus, it is easy to say that family members displaced in search of additional and alternative source of income.

Findings of Kavi and Brinda (2012) showed that individuals with some resources—but not adequate enough might undertake short-term migration to supplement their livelihoods, which was a finding similar to the above table regarding availability of cropland per adult equivalent. Findings of this research revealed that individuals from a household that had larger cropland per adult equivalent could not restrain from displacing. This relationship may be because of less productive cropland to produce the crop what the household demanded.

Climate variability affects household's migration decision only through agricultural channel (Mathilde and Zaneta, 2014), is valid only for households whose income is highly dependent on agriculture, but not for diversified ones. Farming as a primary source of income has failed to guarantee sufficient livelihood for most farming households in developing countries (Babatunde, 2013). Kavi and Brinda (2012) argued that greater weather variability in rural areas increases probability of an individual to undertake short-term migration seeking alternative livelihoods and additional incomes. Table 27 shows that the instrument variables in the random effect 2SLS regression had significant effect on the endogenous variable, crop income. This implies that the climate variability that are instrument covariates to predict the endogenous variable, crop income, from random effect 2SLS regression have indirect effect on rural labor displacement. Crop income reduction through climate variability would significantly increase the number of family members who displaced. Thus, it is easy to generalize that variation in smallholders' crop income due to climate variability elements have significant effect on aggravating the rural labor displacement from central highlands and Arsi grain plough farming systems of Ethiopia.

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1. Summary

The study examined the effect of climate variability on cereals yield, crop income and rural labor displacement in central highlands and Arsi grain plough farming systems of Ethiopia. This work considered eight round unbalanced panel data collected from sample households of the study area starting from 1994 to 2014. The long-run crop season temperature was increasing continuously indicating climate variability problem of the study area. Similarly, there were frequent crop season rainfall inconsistencies within short period intervals.

The stochastic frontier regression result for the sample cereal crops (*teff*, maize, wheat, barley and sorghum) showed that inorganic fertilizer and draught power increment had significant and positive effect on yield of those crops in the two farming systems. The two dominant climate variability elements (cropping season rainfall and temperature) had significant effect on yield of those cereals. The two-climate variability elements had negative and significant effect on smallholders' crop income in the study area. Other covariates like outbreak of diseases and pests, devastating shocks and rainfall inconsistencies affected smallholders' crop yield and income as well.

Additionally, the study examined determinants of smallholders' adaptation strategies to cope climate variability. Based on the regression result distance from the main road, crop price and cropping season rainfall shortage were common factors that affect adoption of the four alternative strategies significantly.

The study also examined effect of climate variability on proportion of family members displaced from the two farming systems. In doing this, smallholders' crop income was instrumented by climate variability elements in order to identify their indirect effect on household members' displacement. Thus, the model result revealed that crop income and other alternative sources of income significantly affect the ratio of household members who displaced from the two farming systems. Owning larger TLU and draught

power significantly reduced the labor displacement and could enable rural labor to create a stable livelihood.

5.2. Conclusions

Long run cropping season rainfall trend of the country showed continuous reduction and there were frequent fluctuations within very short period intervals. In the same fashion, extreme low and high rainfall were also common recently in the two farming systems. In the other direction, cropping season temperature of the country showed continuous increment with the going of time, and there were frequent extreme high temperatures within short period gaps. These all notifies that the global problem, climate change, is also happening in Ethiopia and it would have devastating effect on smallholders who have nature dependent livelihood.

Households in the two farming systems had relatively lower crop productivity as compared to the national average level in all the survey years. The probability of improving their crop productivity and producing more than the national average showed continuous reduction for the cereal crops especially maize and wheat.

Few crops were performing better in some places of the study area where it was not possible to produce them at all before decades. Wheat and barley production showed continuous improvement in cool weather areas of central highlands farming system especially the former one exhibited successive increment implying that the weather condition is becoming auspicious for its production. In contrary to this, the current temperature negatively affected yield of sorghum, maize and *teff*. Thus, smallholders would not be able to produce few crops in the near future if the current temperature increment continuous.

Agricultural inputs like inorganic fertilizer are critical in improving smallholders' cereal yield in the two farming systems. However, successive input price increment was a strong threat to apply the input as to the standard level. Sample smallholders in the study area affirmed that the current time sky rocketing input price rise is going out of their capacity to purchase the production input.

Cropping season rainfall increment positively affected yield of *teff* and barley. Cropping season temperature had negative effect on warm weather cereals production while it affected cool weather ones (wheat and barley) positively. Successive cropping season temperature increment improved yield of wheat and barley while maize, *teff* and sorghum yield decreased significantly in central highlands and Arsi grain plough farming systems of Ethiopia. This may be due to counterbalancing the negative effect of the one with positive brunt of the other, wherein their interaction may create auspicious environment for producing the crops. Further increment of cropping season rainfall and temperature from the current level resulted in mixed effect on cereals yield for households in the two farming systems of Ethiopia.

The rainfall inconsistencies especially in harvesting season, and outbreak of diseases and pests significantly affected smallholders' technical efficiency in producing cereals. Harvesting season rainfall had significant and negative effect on households' technical efficiency to produce all the sample cereals in the two farming systems. Outbreak of diseases and pests would significantly affect technical efficiency of smallholders' to produce wheat, barley, maize and sorghum.

Individual increment in either cropping season rainfall or temperature adversely affected smallholders' crop income in the two farming systems. Rainfall inconsistencies and shocks including, harvesting time rain, late summer onset, early cessation and inconsistent availability in the growing season have strong and negative effect on smallholders' crop income. Consistent availability, but not torrential rainfall within few days, is critical input for amplified crop production and collection of better crop income for households in the two farming systems. Similarly, pest and disease outbreak that may be another dimension of climate variability had negative effect on smallholders' crop income.

Based on their time duration for mitigating climate variability the four alternative adaptation strategies of smallholders in the study area grouped into two broad categories (short-run and long-lasting type). Adopters of the former strategies had lower crop income with better certainty and those households that adopt long-lasting strategies had better crop income with

higher uncertainty. There was also significant difference in crop income generated by households that were adopters and non-adopters of the four alternative strategies.

Distance from the main road and crop price had significant effect on probability of adopting strategies including changing the sowing time and alternative income sources. Households in short distance from all the main roads would have information access to participate in alternative income sources like off- and non-farm activities easily. Similarly, households that suffered from continuous rainfall shortage would likely to adopt those strategies rather than new production technologies and conservation practices that demand larger working capital.

Households in the two farming systems are losing the younger generation who have significant contribution on the future agricultural productivity of the area due to rural labor displacement. Household's crop income improvement significantly reduced the proportion of family members who displaced from the two farming systems. Hence, all the covariates like crop season rainfall and temperature, shocks, outbreak of pests and disease, and others included as an instrument of the endogenous variable for crop income had significant indirect effect on the rural labor displacement from central highlands and Arsi grain plough farming systems of Ethiopia.

Having access to agricultural inputs such as cropland was not a guarantee to reduce proportion of household members who displaced from the two farming systems unless the inputs were productive enough to produce the required amount of income.

In general, the recurrent climate variability is becoming serious bottleneck for Ethiopia to have productive agriculture, and to keep the youths and energetic labor in the rural economy. Given other bottlenecks, if the current rural labor displacement persists longer, achieving the 2025 plan of the country could be under question mark.

Finally, the study identified that rainfall inconsistency in different stages of cereal production and other climate variability sourced shocks resulted in crop yield and income variation as

well as rural labor displacement in central highlands and Arsi grain plough farming systems of Ethiopia.

5.3. Recommendations

Smallholders of the study area had lower crop yield as compared to the national level. This circumstance may be because of remoteness to access agricultural inputs easily. Thus, intensive effort and preferential treatments should be there to enhance productivity of smallholders in remote areas with lower access to infrastructures.

There should be government intervention to reduce the successive fertilizer price increment in order to make it easily affordable for smallholder farmers of the country. If possible, it is better to subsidized smallholder farmers in order to increase application of the input to the standard level.

In order to have consistent water supply *forte*, maize and sorghum that suffer from moisture stress strategies like irrigation and water harvesting should be extensively utilized. Unless there are serious measures the ongoing temperature increment coupled with rainfall inconsistency and climate sourced shocks would have devastating effect on production of those cereals in the two farming systems.

Some of the problems sourced from climate variability are not manageable for smallholders to curve their effect. It may be difficult to manage the complex climate related problems without a coordinated effort that includes comprehensive trainings, information about early warning, drought preparedness plans, and emergency response programs at regional or nation level.

Both material and labor budget should be ready to reduce effect of pest infestation and disease outbreak on smallholders' crop income. In doing this, biological and natural way of protection should be there to reduce external effect of chemicals on the livestock especially beehives of smallholder farmers. Additionally, biological methods are preferable for rural households who do not afford the on-going agricultural input price.

Smallholders of the study area had infrastructure gap in adopting different alternative adaptation strategies. Thus, there should be active participation of institutions and agencies to provide the required facilities that could enhance smallholders' awareness. Supports in this regard could enable smallholders to decide, which agricultural technology and adaptation strategies could be more effective in adapting climate variability.

Being price setter may enable to collect the potential benefits from the merchandises traded. Thus, bargaining power of smallholders should be enhanced to make them crop price setter. Having easy access to market information and other infrastructural facilities could enable them to be active participant in the market. These all would improve smallholders' adaptation capacity to the ongoing climate variability.

Smallholders' income improvement would increase capacity of them to cope up with the effect of climate variability. Thus, to sustain economic growth and reduce smallholders' vulnerability, policy makers should intensify long-lasting adaptation strategies such as soil and water conservation, income diversification and irrigation schemes.

Alternative income sources should be made available to have sustainable livelihood in rural areas to create conducive environment that could reduce displacement of rural youth from their abode. Given this, agricultural policy makers should provide attention on how to create stable crop income for smallholders to reduce the problem of losing the agricultural labor that has the potential energy.

Besides, managing the climate related problems that were the critical push factors, promoting access to saving and off-and non-farm activities in rural areas could reduce labor displacement. There should be awareness creation for smallholders of the two farming systems to increase saving capacity and participation in off- and non-farm activities.

Finally, extreme starvations and poverty that happen occasionally will be frequent problems of the country in extensive area coverage unless coordinated actions done to curb the climate

variability problems. National level policy makers should consider effect of climate variability in formulating both meso and macroeconomic policies to improve agricultural productivity of Ethiopia.

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7. APPENDICES

7.1. List of Tables in the Appendix

Appendix Table1. Survey time of each round

Kebele	Main season	1994a	1994b	1995	1997	1999	2004	2014
Dinki	December	March-April	Nov.	January	October, Nov	Aug	May-June	February-April
D/Berhan	November December	March-April	Oct.	March	June-August	July	April May	February-April
Yetmen	November December	March-April	Oct.	March	Septem. October	June	May June	February-April
SirbanGodeti	November December	March-April	Nov.	March	June, July	June	April May	February-April
Koro-	October November	May-Jun	Nov-Dec	May-June	June, July	Aug	May	February-April
Turfe	December	Mar-April	Sep.-Oct.	Mar-April	Sep-Oct	June	May June	February-April

Appendix Table2. Family size of households

Year	Central highland	Arsi	p-value	Combined Mean
1994a	5.42	6.76	0.000	5.89
1994b	5.42	6.62	0.000	5.81
1995	5.33	6.51	0.000	5.72
1997	5.55	6.50	0.000	5.88
1999	5.25	6.55	0.000	5.68
2004	5.29	6.03	0.001	5.53
2009	5.35	6.11	0.001	5.61
2014	4.42	5.67	0.000	4.97

Source: ERHS (1994a-2009) and survey by the researcher in 2014

Appendix Table3. Crop calendar of each sample sites

Kebeles	Crop	Plough	Planting	Weeding	Harvesting
D/Birhan	Barley	March and April	May and June	August and September	October
	Wheat	March and April	May and June	August and September	October
Dinki	<i>Teff</i>	March, April, May and June	July	August and September	October
	Sorghum	March	April	June and August	November
	Maize	May	July	September	November
Korodegaga	Maize	April	June	October	July
	<i>Teff</i>	April	June	October	July
	Wheat	April and May	July	August	October
	Barley	July	August	September	May
Sirbana	Maize	March	April	May	October
	Sorghum	March	April	May	October
	Wheat	May	June	July and September	October
	Barley	May	June	July and September	October
	<i>Teff</i>	May and June	July and August	September and October	November
Turufe	Wheat	June	July	September	October

	<i>Teff</i>	June and July	August and September	October	November
	Barley	May	June	August	October
	Maize	March	April	May and June	September
	Sorghum	March	April	May and June	October
Yetmen	<i>Teff</i>	April, May and June	July and August	September and October	November
	Wheat	July and August	September	October	November
	Maize	March	April and May	July and August	September

Source: ERHS Ethiopian Village Studies, 2009

Appendix Table4. Conversion factor for man equivalent

Group of years	Male	Female
<10	0	0
10-13	0.2	0.2
14-16	0.5	0.4
17-50	1	0.8
>50	0.7	0.5

Source: Storck *et al.* (1991)

Appendix Table5. Conversion factor used to compute adult equivalent

Group of years	Male	Female
<10	0.6	0.6
10-13	0.9	0.8
14-16	1	0.75
17-50	1	0.75
>50	1	0.75

Source: Storck *et al.* (1991)

Appendix Table6. Number of households suffered from rainfall inconsistencies

Type of crop	Number of households			
	In 1999		In 2009	
	Central highland	Arsi	Central highland	Arsi

<i>Teff</i>	56	62	76	20
Wheat	20	15	22	10
Maize	8	37	14	9
Barley	26	1	12	3
Sorghum	40	2	32	2
Total	150	117	156	44

Source: Own computation from ERHS in 1999 and 2009

Appendix Table 7. Households' participation in soil conservation

Soil fertility improvement methods	(% household in		Type of soil conservation	(% household in	
	1999	2009		1999	2009
Manure	54.83	54.95	Stone bunds indigenous	42.16	54.9
Fallowing	17.44	17.47	Soil bunds indigenous	51.22	27.73
Crop rotation	26.47	26.53	Stone bunds introduced	2.79	6.44
Burning the soil	0.42	0.21	Soil bunds introduced	1.05	0.56
Terrace and others	0.84	0.84	Contour plough	2.79	10.36

Source: ERHS in 1999 and 2009

Appendix Table 8. Overall crop production and yield in the two farming systems

Description	Crop type	Central highland	Arsi	Combined Mean	P-value
Area in hectare	<i>Teff</i>	0.95	0.86	0.91	0.000
	Barley	0.91	0.30	0.72	0.000
	Wheat	0.43	0.48	0.44	0.000
	Maize	0.20	0.61	0.46	0.000
	Sorghum	0.48	0.08	0.37	0.000
Production in kg	<i>Teff</i>	932.69	405.11	698.82	0.000
	Barley	736.50	321.58	617.30	0.000
	Wheat	405.78	673.38	497.57	0.000
	Maize	223.17	542.28	452.40	0.000

	Sorghum	378.25	243.80	357.30	0.000
Yield in kg/ha	<i>Teff</i>	979.57	621.63	820.90	0.000
	Barley	939.56	978.72	950.81	0.317
	Wheat	1068.56	1262.20	1134.97	0.000
	Maize	1183.06	1174.82	1177.14	0.899
	Sorghum	697.61	1252.04	783.98	0.000

Source; ERHS from 1994a-2009 and own data 2014

Appendix Table 9. Comparison of national level yield with sample households

Description	Crop type	Sample year						
		1994a	1995	1997	1999	2004	2009	2014
National level	Teff	7.5	8.35	7.48	8.09	9.48	12.28	15.75
	Wheat	11.67	12.20	14.05	11.83	15.57	18.25	25.43
	Maize	15.5	19.83	17.53	17.95	17.19	21.99	34.39
	Barley	11.5	10.57	11.53	9.34	12.12	15.5	19.65
	Sorghum	12.5	13.75	11.2	11.87	13.69	18.69	23.69
Sample households	Teff	6.38	7.03	8.58	7.66	8.90	8.02	12.85
	Wheat	8.99	8.69	13.15	10.28	11.62	12.73	18.39
	Maize	11.44	13.96	16.62	9.62	12.10	19.46	19.36
	Barley	12.41	10.56	11.05	9.52	9.28	14.24	18.17
	Sorghum	7.19	3.67	10.81	8.82	8.75	11.95	16.20

Source: Own computation and CSA, 2015

Appendix Table 10. Smallholder's participation non- and off-farm activities

Year	Farming system	Type of Activity						Total
		Milling	Handicraft	Livestock & crop trading	Traditional healer	Collect firewood	Others	

1994a	Central	3	79	23	9	220	9	343
	Arsi	0	13	20	2	62	16	113
1999	Central	1	44	28	0	32	80	209
	Arsi	0	40	12	0	108	62	222
2004	Central	17	67	69	18	48	18	237
	Arsi	0	8	16	1	66	1	92
2009	Central	19	111	59	17	95	38	339
	Arsi	3	24	17	2	24	7	77

Source: ERHS from 1993-2009.

Appendix Table 11. Probability of changing cropland, production and yield

Crop type	Description	Overall		Central highland		Arsi grain	
		1999	2009	1999	2009	1999	2009
Teff cropland	1999	85.17	14.83	85.17	14.83	81.89	18.11
	2009	29.65	70.35	29.65	70.35	16.90	83.10
	Total	61.76	38.24	61.76	38.24	58.59	41.41
Maize cropland	1999	40.46	59.54	26.32	73.68	55.81	44.19
	2009	36.82	63.18	33.14	66.86	37.50	62.50
	Total	37.99	62.01	31.90	68.10	45.45	54.55
Wheat cropland	1999	53.57	46.43	60.00	40.00	51.43	48.57
	2009	24.54	75.46	29.30	70.70	30.67	69.33
	Total	31.60	68.40	37.83	62.17	34.34	65.66
Teff production	1999	56.61	43.39	64.00	36.00	41.46	58.54
	2009	36.07	63.93	40.00	60.00	29.31	70.69
	Total	45.59	54.41	51.43	48.57	34.34	65.66
Maize production	1999	37.23	62.77	25.93	74.07	45.26	54.74
	2009	41.70	58.30	31.15	68.85	49.51	50.49
	Total	40.20	59.80	30.48	69.52	47.47	52.53
Wheat production	1999	80.46	19.54	79.62	20.38	82.42	17.58
	2009	32.12	67.88	29.34	70.66	36.45	63.55
	Total	57.47	42.53	57.41	42.59	57.58	42.42

Teff yield	1999	59.24	40.76	48.94	51.06	52.00	48.00
	2009	29.48	70.52	32.76	67.24	21.14	78.86
	Total	40.93	59.07	40.00	60.00	32.83	67.17
Maize yield	1999	49.25	50.75	33.33	66.67	58.95	41.05
	2009	29.56	70.44	26.78	73.22	33.01	66.99
	Total	36.03	63.97	27.62	72.38	45.45	54.55
Wheat yield	1999	80.46	19.54	79.62	20.38	82.42	17.58
	2009	32.12	67.88	29.34	70.66	36.45	63.55
	Total	57.47	42.53	57.41	42.59	57.58	42.42

Source: Own calculation, 2017

Appendix Table 12. Average technical efficiency in the two farming systems

Crop type	Central highland	Arsi grain plough	Combined average	t-value
<i>Teff</i>	0.532	0.381	0.459	18.63***
Wheat	0.349	0.456	0.385	14.76***
Maize	0.893	0.805	0.830	8.01***
Barley	0.459	0.493	0.469	4.36***
Sorghum	0.559	0.589	0.576	25.66***

Source: own conversion, 2016

Appendix Table 13. Stock-Yogo weak ID test critical values based on TSLS bias

K ₂	n=1,b=				n=2,b=				n=3,b=			
	0.05	0.10	0.20	0.30	0.05	0.10	0.20	0.30	0.05	0.10	0.20	0.30
3	13.91	9.08	6.46	5.39								
4	16.85	10.27	6.71	5.34	11.04	7.56	5.57	4.73				
5	18.37	10.83	6.77	5.25	13.97	8.78	5.91	4.79	9.53	6.61	4.99	4.30
6	19.28	11.12	6.76	5.15	15.72	9.48	6.08	4.78	12.20	7.77	5.35	4.40
7	19.86	11.29	6.73	5.07	16.88	9.92	6.16	4.76	13.95	8.50	5.56	4.44
8	20.25	11.39	6.69	4.99	17.70	10.22	6.20	4.73	15.18	9.01	5.69	4.46
9	20.53	11.46	6.65	4.92	18.30	10.43	6.22	4.69	16.10	9.37	5.78	4.46
10	20.74	11.49	6.61	4.86	18.76	10.58	6.23	4.66	16.80	9.64	5.83	4.45
11	20.90	11.51	6.56	4.80	19.12	10.69	6.23	4.62	17.35	9.85	5.87	4.44
12	21.01	11.52	6.53	4.75	19.40	10.78	6.22	4.59	17.80	10.01	5.90	4.42
13	21.10	11.52	6.49	4.71	19.64	10.84	6.21	4.56	18.17	10.14	5.92	4.41
14	21.18	11.52	6.45	4.67	19.83	10.89	6.20	4.53	18.47	10.25	5.93	4.39
15	21.23	11.51	6.42	4.63	19.98	10.93	6.19	4.50	18.73	10.33	5.94	4.37
16	21.28	11.50	6.39	4.59	20.12	10.96	6.17	4.48	18.94	10.41	5.94	4.36

17	21.31	11.49	6.36	4.56	20.23	10.99	6.16	4.45	19.13	10.47	5.94	4.34
18	21.34	11.48	6.33	4.53	20.33	11.00	6.14	4.43	19.29	10.52	5.94	4.32
19	21.36	11.46	6.31	4.51	20.41	11.02	6.13	4.41	19.44	10.56	5.94	4.31
20	21.38	11.45	6.28	4.48	20.48	11.03	6.11	4.39	19.56	10.60	5.93	4.29
21	21.39	11.44	6.26	4.46	20.54	11.04	6.10	4.37	19.67	10.63	5.93	4.28
22	21.40	11.42	6.24	4.43	20.60	11.05	6.08	4.35	19.77	10.65	5.92	4.27
23	21.41	11.41	6.22	4.41	20.65	11.05	6.07	4.33	19.86	10.68	5.92	4.25
24	21.41	11.40	6.20	4.39	20.69	11.05	6.06	4.32	19.94	10.70	5.91	4.24
25	21.42	11.38	6.18	4.37	20.73	11.06	6.05	4.30	20.01	10.71	5.90	4.23
26	21.42	11.37	6.16	4.35	20.76	11.06	6.03	4.29	20.07	10.73	5.90	4.21
27	21.42	11.36	6.14	4.34	20.79	11.06	6.02	4.27	20.13	10.74	5.89	4.20
28	21.42	11.34	6.13	4.32	20.82	11.05	6.01	4.26	20.18	10.75	5.88	4.19
29	21.42	11.33	6.11	4.31	20.84	11.05	6.00	4.24	20.23	10.76	5.88	4.18
30	21.42	11.32	6.09	4.29	20.86	11.05	5.99	4.23	20.27	10.77	5.87	4.17

Source: James H. Stock and Motohiro Yogo, nd. Testing for Weak Instruments

Appendix Table 14. Technical efficiency trend of the two farming systems

Year	Central highland					Arsi grain plough				
	Teff	Wheat	Barley	Maize	Sorghum	Teff	Wheat	Barley	Maize	Sorghum
1993	0.510	0.295	0.348	0.635	0.559	0.327	0.447	0.402	0.606	0.588
1994	0.237	0.409	0.337	0.438	0.559	0.318	0.186	0.274	0.643	0.588
1995	0.502	0.304	0.386	0.781	0.559	0.339	0.456	0.483	0.731	0.588
1997	0.504	0.327	0.421	0.776	0.559	0.361	0.417	0.431	0.766	0.590
1999	0.519	0.337	0.453	0.832	0.559	0.382	0.460	0.413	0.851	0.588
2004	0.540	0.369	0.525	0.941	0.560	0.408	0.557	0.533	0.943	0.590
2009	0.556	0.397	0.609	0.981	0.560	0.439	0.518	0.582	0.978	0.590
2014	0.565	0.459	0.687	0.991	0.561	0.448	0.464	0.632	0.990	0.591
Average	0.523	0.349	0.459	0.893	0.559	0.381	0.456	0.493	0.805	0.589

Appendix Table 15. Yearly migration level in each sample villages

Year	Dinki	Yetmen	Sirbana	Koro	Turufe	D/Birhan	Total Migrant
1993	26	12	30	35	33	56	192
1994	19	0	1	61	73	67	221
1995	9	3	26	25	35	41	139
1997	23	23	41	51	50	78	266
1999	25	16	38	16	22	42	159
2004	15	12	43	22	28	46	166
2009	51	24	54	67	63	105	364
2014	13	19	24	15	23	52	146
Total	181	109	257	292	327	487	1653

Source: ERHS from 1993-2009 and survey of the researcher in 2014

7.2. Survey Questionnaire

Household Sample Survey Interview Schedule

On

Effects of Climate Variability on Crop Yield, Income and Rural Labor Displacement in
Ethiopia

PhD Dissertation Research Project

School of Graduate Studies

Haramaya University

1. Research Area and Household Related

- 1.1.Name of the district-----
- 1.2.Name of the *kebele*-----
- 1.3.Name of the household head-----
- 1.4.Distance from the nearest market-----km(hour)
- 1.5.Distance from the main road-----km(hour)
- 1.6.Communication center-----km(hour)

2. Institutions

- 2.1. Have accessto electricity? A) yes B) No
- 2.2. If your answer for the above question is B what is your source of electricity?_____

2.3. Have you access to piped water? A) yes B) No

2.4. If your answer for the above question is B what is your source of water?_____

3. Demographic Characteristics

No	Name of family member	Educational level	Age	Sex	Relation to the head	Occupation	Marital status		
							Single	Divorce	Separated
1									
2									
3									
4									
5									
6									
7									
8									

4. Labor related information (human and animal labor)

4.1. Human labor

4.1.1. How many of your family participate on the agriculture? Male ----- Female -----

Name	Age	Sex	Type of work done	No of hours per day	No of days in a month

4.1.2. Did you hire in labor from outside to work on your own land? A)Yes B) No

4.1.3. Number of people involved_____ Total number of days worked_____ Total payment (cash payments)_____ Total payment in kind_____

4.1.4. Was your output affected because of someone in the family was too ill at critical periods of the farm operation? A) Yes B) No

4.2. Draught power related

4.2.1. What is your source of draft power? A) Oxen B) Other machineries

4.2.2. How many pair of oxen do you have? _____.

4.2.3. If your answer for question no4.2.1 is A to whom the oxen belongs?

A) Yours B) Rent in cash C) Rent in kind D) Share work

4.2.4. If you have surplus oxen power; how you utilize that power? A)Renting B)Working in share

4.2.5. How much do you receive for the surplus labor that you rent out in the previous year?_____.

4.2.6. How much did you get when you give your oxen for share?__Birr. __quintal.

4.2.7. Do you face shortage of draft power? A) Yes B) No

4.2.8. If it happens, how do you cope up the problem?_____

4.3. Other Expenditures on Agricultural Inputs

Type of expenditure during the previous season

Input type		Where did you buy the input? (e)	Total payment in cash (Birr)	How much did you use in kg in the previous crop season?
Fertilizer	DAP			
	Urea			
Pesticides (fungicides & herbicides)				
Seeds and young plants				
Labor for crop production				
Transport cost to crop production				
Rent for oxen				
Tractor, harvester, or combine services				
Others (specify _____)				

4.3.1. Was your output affected because of not getting fertilizer at the right time?

A) Yes B) No

4.3.2. What remedial actions you took? _____

5. Livestock Related Questions

5.1. List out your livestock structure

Type of animal	No at the beginning	New born	Died	Sold	Bought	Total at the end
Oxen						
Cow						
Bull						
Heifers						
Camel						
Sheep						
Goats						
Horse						
Donkey						
Ewe						
Doe						
Others						

5.2. Did any of your livestock suffer from any of the following factors in the previous year?

Moderately _____. Severely _____. Not at all _____

6. Land particular

6.1. Indicate the land and the crop type that you sow last year.

Type of crop	Amount of land for the crop	Distance from your	Ownership type		
			Own	Rented in	Shared (ha)

		home	(ha)	cash(ha)	In (ha)	Out (ha)

6.2. How much land do you have for grazing? -----

6.3. How much land did you fallow last year? -----

6.4. What is the main problem related to land?

- A) Land shortage. The possible solution-----
- B) Water shortage. Possible solution.-----
- C) Over flooding of water. The possible solution -----
- D) Low land productivity. The possible solution -----
- E) Decreasing the fertility of land
- F) Land slipping. The possible solution-----
- G) Shortage of rainfall. The possible solution-----
- H) Late start of the rain. The possible solution-----
- I) Early setoff of the rain. The possible solution-----
- J) Other reasons.-----

7. Crop production

7.1. When did you start farming? -----e.c

7.2. How many years you spent while you are a farmer? -----years

7.3. What is the main problem in the crop production process?

- A) Land size
- B) Rainfall shortage
- C) Temperature average
- D) Draft power shortage
- E) Human labor shortage
- F) Natural factors
- G) Other factors

7.4. How much quintal of yield you gain per-hectare? From the different crops.

From Maize____, Sorghum____, Wheat____, Barley____, Potato____, others____,

7.5. Is there any effort that you make to improve your cropland? A) Yes ☐ B) No ☐

7.6. If yes how much money do you pay for the activities?_____

7.7. Do you have access to extension services? A) Yes ☐ B) No ☐

7.8. If your answer for the above question is yes, how frequent are you visited by development agents? A) Once a year B) Twice a year C) Three times a year D) More than three times

7.9. If your answer for the above question is No; what is the possible reason?

- A) The distant location of your farm
- B) Absence of qualified persons
- C) Any other possible reasons
- D) You don't want their support

7.10. Did you face market problem for your output? If yes; what is the reason?

- A) Poor quality of your produce
- B) Distance location from the market
- C) Absence of transporting facilities
- D) Absence of demanders
- E) other reasons

7.11. Which type of crop do you like to cultivate mostly? Orderly 1_____,
2_____, 3_____, 4_____, 5_____, 6_____

7.12. Why do you prefer as such a like? _____

7.13. Requirement of inputs by each crop

Input type	Measurement unit	Crop type						
		Sorghum	Maize	Wheat	Barley	Teff	Vegetable	Others
Land								
Dap								
Urea								
Chemical for Weed								
Pesticide								
Insecticide								
Compost								

7.14. What is the main problem that you face when you use agricultural inputs?(You can choose more than one).

- A) Repetitive price increment E) Absence of knowledge on how to use
B) Shortage of supply F) Shortage of money to purchase inputs
C) Increment of transport cost G) other reasons
D) Absence of loan to purchase inputs

7.15. Did you have produced crop in both the two season? A) Yes B) No

7.16. When did you face the problem of rainfall shortage? _____

7.17. Are there crops that you had produced in the previous times but you can't produce in the present times? A) Yes B) No If yes please list them _____

7.18. Is there reduction in the land coverage that you had allocated for crops?

- A) Yes B) No

7.19. Are there permanent crops that you lost with the going of time? A) Yes B) No If yes what were the reasons?_____

7.20. Do you have modern hybrid crops that you adopt? A) Yes B) No

7.21. What are the reasons of using those crops? A) Productivity B) Drought resistivity C) Market reason D) Short period of cultivation.

7.22. Do you feel that the environment has undergone significant change in your life?

- A) Yes B) No

7.23. If your answer for the above question is yes, what possible signs do you observe about such change? A) Decreasing the amount of rain D) Increasing temperature
B) Fluctuation of rain fall like late start and early stoppage E) Occurrence of flooding
C) Occurrence of frost and drought F) Any other possible reason

8. Monthly Expenditure on Consumption Particulars

8.1. What is your main staple food? _____, _____, _____

8.2. What is the source of that staple food? _____, _____, _____

8.3. How much amount of each crop that you produce budgeted to consumption?

Crop type	Total crop produced (kg)	Crop consumed (kg)	Price per (kg)	Total value	Amount from purchased(kg)
Teff					
Barley					
Wheat					
Maize					
Sorghum					
Millet					
Lentils					
Horse Beans					
Cow Peas					
Chick Peas					
Milk/yoghourt					
Beef					
Mutton					
Chicken					
Eggs					
Butter/cheese					
<i>K'at</i>					
Coffee					
Sugar					
Honey					
Salt					
Cooking oil					
Spices					
Bread					
Macaroni/spaghetti					
Potatoes					
<i>Enset</i>					
Sweet potatoes					
Green leafy vegetables					

8.4. Are you food self-sufficient with the crops that you produce? A) Yes B)No

8.5. If you say no; how you do fill the gap for the additional food requirement?

A) Purchase B) Aid C) other means

8.6. Did you receive food aid from government or any other donor in the previous production year? A)Yes ☐ B)No ☐

8.7. If you say yes for the above question how much was the amount-----and-----price.

8.8. How much money do you spend per month for your livelihood?

A) For food _____ D) For purchase of implements _____

B) For health care _____ E) For others _____

C) For purchase of inputs and pesticides_____

9. Selling particulars

9.1. How much income did you get per month from different sources?_____

9.2. What is your main source of income? A) Crop production B) Animal husbandry C) Both

9.3. When do you sell your crop products?

A) After harvest

C) On other time

B) When there is increment in price (especially in the summer season).

9.4. Selling structure of the previous year

Crop type	Average price	Amount sold (qui.)	Amount purchased (qui.)	Resold	Total sell
Maize					
Sorghum					
Wheat					
Barely					
Teff					
Beans					
Peas					
Potato					
Coffee					
Oil seeds					
Vegetables					
Others					

9.5. Did you harvest any crop residue in the last agricultural year?

9.6. From which crop? crop code (b) How much did you earn from selling crop residue? (Birr) ____

9.7. Animal and animal products selling

Animal and animal products	Average price	Type of animal or product sold	Purchased	Resold	Total sell

9.8. What method of transportation do you use? A) Animal B) Truck C) others

9.9. Is the price that you get for the crop /cattle or others are satisfactory? Yes ☐ No ☐

9.10. If you say no, what are the possible reasons for the low price? -----

10. Credit related

10.1. Do you have access to banks or any other credit marketing organization? A) Yes B)No

10.2. Are you familiar in getting loan? A) Yes B) No

10.3. Source of loan A) Moneylender B) Relative C) Friend/neighbor D) From *equb* or *iddir* E) from the cooperative F)bank G) from a bank H) others

10.4.If you say yes for the above question; what did you do with the credit? -----

10.5.Why no loan was taken?

A) No need for a loan

C) No-one available to get a loan D) Tried to get a loan but was refused

E) I have no assets for collateral F) Afraid of losing collateral

G) Afraid that i cannot pay back H) Interest rates too high

10.6.Do you have habit of saving? A) Yes B) No If yes; fill the table.

10.7. What is the main purpose of saving? -----.

11. Off-farm employment opportunities

11.1. Do you have any experience to practice activities out of your agriculture last year?

A)Yes

B)No

11.2. If the answer for the above question is yes, fill the following table.

Type of off-farm activity	Monthly payment	Duration of work (month)	In which season you work	No hours per-day

11.3.In the last year, did you or any other members of the household work off, against payment in cash or in kind, including as part of food for work? A) Yes B) No

11.4. Total amount earned in the last four months. If in kind, give amount, form of payment and unit. Amount (in Birr)_____, Amount (in kind)_____.

11.5.In the last year, how many months have you been involved in this activity for more than 5 days (number)

11.6.In the last year, did you or any other members of the household who are ≥ 15 years old temporarily migrate to a place outside this *kebele* in order to look or undertake work?

A) Yes

B) No

11.7.Have you or other members of your household been involved in any of the activities listed below in last year? A) Yes B) No. If your answer is yes, choose at least three.

1. Weaving/spinning

6. Handicraft, including pottery

2. Collecting, selling firewood or dung cakes

7. Transport (by pack animal)

3. Trade in livestock/livestock prod.

8. Milling

4. Trade in grain/general trade (incl. banana, pepper, honey, etc.)

5. Other activities? Specify

11.8. Total amount of income in birr (in the last year)_____. Amount in kind_____

12. About labor migration

12.1. Is there an individual who leaved/migrate the household? A)Yes B) No. If yes please fill the following table

Name of the migrant	Year of leaving the HH	Why did he leave? Code (a)	Where does he currently live? Code	What is his current occupation?	Was he younger than 15 when he left? Code (d)
---------------------	------------------------	----------------------------	------------------------------------	---------------------------------	---

			(b)	Code (c)	

- 12.2. What was the reason for him/her? A) Reduction in the agricultural productivity
B) Household related problems C) To collect additional income D) Social problem
- 12.3. If the reason for the migration is reduction in the agriculture productivity, what was the reason? A) Due to heavy rainfall B) Drought C) Flood D) Wind E) Landslide
- 12.4. How much was the remittance income collected the migrated from relative? ___birr per year. If it was in kind what was the estimated amount in terms of cash _____birr.
- 12.5. Do people from this community migrate for work at certain times of the year?
A. Yes B. No
- 12.6. Where do people usually go? (Write the region below and indicate if this is migration to an urban area) Urban
- 12.7. What type of work do they usually look for? A) Agriculture B) Non-agriculture
- 12.8. Do people from other communities migrate into this community for work at certain times of the year? A. Yes B. No
- 12.9. Since E.C. 1996, have more people moved to this community, or have more people moved away? 1 More arrivals than departures, 2 More departures than arrivals, 3 About the same, 4 Neither

13. Adaptation mechanisms

- 13.1. Do you perceive that there is increment in temperature? A) Yes B) No
- 13.2. If your answer for the above question is yes, how it affects your crop production? A) Reduction B) Complete damage C)
- 13.3. What was the remedy you took? A) Collecting for cattle feed B) Just you leave as organic fertilizer C)
- 13.4. How do you adapt the problem? A) No adaptation (mono-cropping) B) Planting different crops and/or varieties C) Change planting date D) other adaptations.
- 13.5. Did you face rainfall shortage in the previous ten years? A) Yes B) No
- 13.6. If your answer for the above question is yes, what was the direction?
A) Late start B) Early stops C) Oscillation in the season D)
- 13.7. What did you do if there is late start? A) Changing the crop type B) Change planting date C) Simple saw the crops what you have D) Other adaptation mechanisms
- 13.8. Have you adopted new crops that you did not cultivate in previous years? A) Yes B) No
- 13.9. If your answer for the above question is yes, please list them _____
- 13.10. Why do you adopt those new crops _____
- 13.11. Did you face heavy rainfall in the previous ten years? A) Yes B) No
- 13.12. What was the impact on your crop production? A) Reduction B) Complete damage

14. Water related

14.1. What is your main source of water for the crop production?

- A) Rain fall B) Irrigation C) Stream
D) Ponds E) Marshy areas F) Self water harvest

14.2. Do you have a plot of land that is out of production because of rain fall shortage? A)

Yes B) No. If yes, what was the measure that you took? _____

14.3. If your answer for the above question is yes, for what purpose you use that plot?

- A) Grazing land B) Constructing house C) Any other activities _____

14.4. Did you use pond water?

For which crop	Season of usage (month)	Reason of preferring this crop

14.5. Did you face water (moisture) shortage for your crops? A)Yes B) No

14.6. If your answer for the previous question is yes how much you lose? _____ (qu.)

14.7. Which of the crop you sow when the rain does not come on time? _____

14.8. What are your responses when there is early lapse of rain? _____

14.9. For how many years do you face as such rainfall oscillation? _____

14.10. Which direction of oscillation is common? A) Late start of rain B) Early lapse of rain
C) Insufficient amount of rain D) High temperature E) other reason

14.11. Which of the crops were more sensitive? _____

15. Shocks

15.1. Which of the following events happened that affects growth and harvest of your crops?

15.2. Are the summer rains important for your crops? A)Yes B)No

15.3. Was there enough rain on your fields at the beginning of the rainy season? A)Enough
B) Too little C) Too much

15.4. Was there enough rain on your fields during the growing season? A)Enough
B) Too little C) Too much

15.5. Did the rain stopped on time in the previous production year? A) On time
B)Stopped too late C)Stopped too early D)

15.6. Was there rain near the harvest time? A)Yes B)No

Code (a) What did these shocks result	Code (b), How widespread was shock?
Loss of productive assets	Only affected my household
Loss of household income	Affected some households in this village
Reduction in household consumption	Affected all households in this village
Asset & income loss	Affected this village and other villages nearby
Asset loss & reduced consumption	Affected areas beyond this kebele.
Income loss & reduced consumption	
Asset, income loss & reduced consumption	
Other effects not listed here.	

15.7. Has this household been affected by a serious shock an event that led to a serious reduction in your asset holdings, caused your household income to fall substantially or resulted in a significant reduction in consumption? The worst shocks in the last 5 years.

Specifics of shock	1 Yes 2 No	In what years did these shocks occur?	Did these shocks result in: Code (a)	How widespread was this shock? Code (b)
Drought				
Low temperatures				
Too much rain or flood				
Erosion				
Frosts or hailstorm				
Pests or diseases that affected crops				
Pests or diseases that affected livestock				
Lack of access to inputs or in increase prices				
Large decrease in output prices				
Lack of demand or inability to sell agricultural products				
Lack of demand or inability to sell nonagricultural products				
Wind/storm				
Weed damage				
Confiscation of assets				
Theft of cash				
Theft of crops				
Theft of livestock				
Theft or destruction of housing or consumer goods				
Crime resulting in death or disablement of adult household members				
Death of husband				
Death of wife				
Death of another person				
Illness of husband				
Illness of wife				
Illness of another person				
Divorce, separation or abandonment				
Disputes with neighbors				

15.8. Thinking about the last ten years, what were the three most important shocks to affect this household?

1st _____
2nd _____
3rd _____

The end !!!