ADDIS ABABA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

ECONOMIC IMPLICATIONS OF CLIMATE CHANGE IN ETHIOPIA: A COMPUTABLE GENERAL EQUILIBRIUM ANALYSIS

BY

ASHENAFI BELAYNEH AYENEW

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ECONOMIC IMPLICATIONS OF CLIMATE CHANGE IN ETHIOPIA: A COMPUTABLE GENERAL EQUILIBRIUM ANALYSIS

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Master of Science in Economics (Resource and Environmental Economics stream)

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"Economic Implications of Climate Change in Ethiopia: A Computable General Equilibrium Analysis"

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Ashenafi Belayneh Ayenew

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ACRONYMS

AEZ	Agro-ecological Zone
AOGCM	Atmospheric-Oceanic Global Circulation Model
CCC	Canadian Climate Center
CES	Constant Elasticity of Substitution
CET	Constant Elasticity of Transformation
CGCM2	Coupled Global Climate Model
CGE	Computable General Equilibrium
CO_2	Carbon Dioxide
EDRI	Ethiopian Development Research Institute
EV	Equivalent Variation
FAO	Food and Agriculture Organization
FCU	Foreign Currency Units
GDP	Gross Domestic Product
GFDL	Geophysical Fluid Dynamics Laboratory
GHG	Greenhouse Gases
HadCM3	Hadley Centre Coupled Model
HDI	Human Development Index
IPCC	Intergovernmental Panel on Climate Change
LCU	Local Currency Units
MDG	Millennium Development Goals

MoARD	Ministry of Agriculture and Rural Development
MoFED	Ministry of Finance and Economic Development
NBE	National Bank of Ethiopia
NMA	National Meteorological Agency
NMSA	National Meteorological Services Agency
PANE	Poverty Action Network of civil society organizations in Ethiopia
PASDEP	A Plan for Accelerated and Sustained Development to End Poverty
PCM	Parallel Climate Model
SAM	Social Accounting Matrix
SRES	Special Report on Emission Scenarios
UNDP	United Nations Development Program

ABSTRACT

Climate change has become one of the pressing problems worldwide as it affects socio-economic activities - agriculture being one of the most vulnerable sectors. Specifically, this study has attempted to evaluate the short-run economic impacts of climate change (change in the levels of temperature and precipitation) with a focus on the Ethiopian economy. In so doing, it uses a computable general equilibrium model based on the 2005/06 Ethiopian Social Accounting Matrix. The results show that climate change has a dampening effect on economic growth and many key macroeconomic indicators. Investment is the only macroeconomic variable that increases despite the changes in climate. It has also a negative impact on sectoral growth and trade, and the effect varies across agro-ecological zones. The findings further revealed that household livelihoods (measured in terms of income and welfare) have declined, and the effect is unevenly distributed across different household groups. The highest losses are likely to be incurred by the poor households that are residing in smaller urban centers. Thus, the results of the study calls for improved climate adaptation actions to reduce both economic decline and welfare deteriorations.

CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

Ethiopia is one of the least developed countries in the world with about 30% of its population living under the national poverty line (MoARD, 2010). Its human development index (HDI) is 0.414; ranking 171st out of 182 countries (UNDP, 2009). Hence, poverty which is associated with high population growth, low level of institutional setups and backward technology employed especially in the agricultural sector is the main social challenge to sustainable development in the country (World Bank, 2008; Deressa, 2010). In addition, development in the country is also challenged by several environmental problems (NMA, 2007; World Bank, 2008; MoFED, 2010b).

The Ethiopian economy heavily depends on agriculture. Moreover, with a total area of about 1.13 million km^2 and 51.3 million hectares of arable land, the country has tremendous potential for agricultural sector development. However, only about 11.7 million hectares of land are currently being cultivated; just over 20% of the total arable area. Cereals dominate the country`s agriculture followed by livestock production, accounting the lion's share of agricultural gross domestic product (GDP) (MoARD, 2010).

As in most developing countries, agriculture in Ethiopia is also dominated by smallholder farming. It absorbs about 11.7 million smallholder households. These

households account for about 95% of agricultural GDP and 85% of employment. About 25% of these households earn some income from non-farm enterprises, but less than 3% rely entirely on income from such enterprises (Ibid). Moreover, the sector is dominated by subsistence, low input-low output, rain-fed farming system with very limited areas of irrigation (Deressa, 2006; Deressa and Hassan, 2009; MoARD, 2010). The use of chemical fertilizer and improved seeds is quite limited and almost 55% of the smallholder farmers operate on a hectare of land or less (MoARD, 2010).

The performance of the sector has been very weak over the last few decades (Deressa, 2006; Deressa and Hassan, 2009; Deressa, 2010). As a result, it left the country dependent on food aid as food security remains a critical issue for almost half of the population (World Bank, 2006), and for the country as a whole (World Bank, 2006; Deressa, 2010; MoARD, 2010). A lot of factors are responsible for such performance of the agricultural sector including: traditional farming practices; tenure insecurity; policy constraints; soil degradation caused by overgrazing and deforestation; insufficient complementary services like extension, marketing, credit and infrastructure; and climate related problems -especially recurring droughts (Deressa, 2006; Deressa and Hassan, 2009; Deressa, 2010).

Ethiopia enjoys an extremely diversified climate condition that ranges from semi-arid desert to humid and warm type across its different parts (NMSA, 2001). To this end, there are different ways of classifying the country's climate systems into a number of agro-ecological zones (AEZs). Across its AEZs, there is a wide variation in mean annual

rainfall and temperature, and daily maximum and minimum temperature levels (NMSA, 2001; NMA, 2007). Besides, the county's climate is also characterized by a history of climate extremes, such as drought and flood, and changing trends in temperature and precipitation patterns. The trend in average annual maximum (NMSA, 2001) and minimum (NMSA, 2001; NMA, 2007) temperature levels have also been increasing in the country.

1.2 Statement of the Problem

Strong evidences now suggest that increased atmospheric concentration of greenhouse gases (GHGs) will have significant impact on the Earth's climate in the coming decades (Mendelsohn *et al.,* 1994; NMSA, 2001; NMA, 2007; IPCC, 2007a; Egnonto and Madou, 2008). Reports by Intergovernmental Panel on Climate Change (IPCC) provided the estimated impacts that would persist on different climate variables under alternative emission scenarios. For instance, assuming no emission control policies, it predicted that average global surface temperatures will increase by 2.8ºC on average during the current century, while the best-guess increases ranging between 1.8 and 4.0ºC (IPCC, 2007a). This increase would alter the natural environmental systems by increasing the frequency of extreme weather events (such as floods and drought), mounting sea levels, changing precipitation patterns and reversing ocean currents. The impacts of these changes on socio-economic activities could have serious long-term implications for the well-being of humans (Zhai *et al.,* 2009; Zhai and Zhuang, 2009).

Agriculture remains to be one of the most vulnerable sectors to the estimated changes in climate conditions despite the technological advances achieved in the second half of the 20th century (Zhai *et al.,* 2009; Zhai and Zhuang, 2009). Projected changes in temperature and rainfall patterns, as well as the consequential impacts on water availability, disease, pests, floods and droughts are all likely to have significant effects on potential agricultural production (IPCC, 2007b; Zhai *et al.,* 2009; Zhai and Zhuang, 2009). In addition, the level of atmospheric carbon dioxide (CO_2) concentration alone can also affect plant growth positively through its effect on photosynthesis levels - direct impact (Cline, 2007; IPCC, 2007b; Matarira, 2008; Zhai and Zhuang, 2009).

The effect of climate change on the agricultural sector, however, is unevenly distributed across regions in the world. Low-latitude and developing countries are expected to be more adversely affected due to their geographical location, the greater share of agriculture in their economies, and their limited ability to adapt and cope with the impacts of climate change, while high-latitude countries are expected to benefit in terms of crop production (NMA, 2007; Zhai *et al.,* 2009; Zhai and Zhuang, 2009). In areas where crops are grown near their maximum temperature tolerance level and where dry land, non-irrigated agriculture predominates, the impact of climate change could be very severe as compared to their counterparts (Parry, 2007).

Cline (2007) predicted that global agricultural productivity will be reduced by 15.9% by the 2080s under the customary warming, with developing countries experiencing a disproportionately large decline of 19.7% of its total agricultural production. The

African continent is expected to experience the brunt of these losses (Cline, 2007); these are attributed to the technological, resource and institutional constraints imposed on these economies. As one of the developing nations, Ethiopia is thus not an exception as exposure to the effects of climate change. In addition, the impact may further be exacerbated by its huge dependence on rain-fed agricultural production, high population growth, insufficient climate-related information and poverty-which significantly reduces the capacity to mitigate, adapt or cope with the various effects of climate change.

Although it is vulnerable to climate change, agriculture still remains by far the most important sector in Sub-Saharan Africa being central tool towards economic growth and most of economic activities in the region are still dependent on agricultural expansion. In most of Africa about 80 % of people are employed in the agricultural sector, posing it to be one of the driving forces of the economy, with GDP contributions of 30 to 60% (Egnonto and Madou, 2008). Similarly, the importance of the sector is undeniable in the Ethiopian economy given that it is contributing about 43% to the country`s GDP, generating about 90% of export revenues *(*MoARD, 2010), and supplying more than 70% of raw materials for agro-based domestic industries (Deressa, 2006; MoFED, 2007). In addition, it is also the major source of food and employment for the population (NMSA, 2001). As a result, any shock on this sector would have wider economic repercussions that can be felt both at macro and microeconomic levels.

So far, some attempts have been done to quantify the likely impact of climate change on agriculture in developing nations. It is a new area of research in Africa in which there are only limited studies (Molla, 2008; Kurukulasuriya and Mendelsohn, 2008). As is the case in other African countries, a few studies (e.g. Deressa, 2006; Molla, 2008; Deressa and Hassan, 2009) assessed the impact of climate change on agricultural production in Ethiopia. However, these studies have the following shortcomings. First, they made use of a partial equilibrium analysis, i.e., Ricardian model, which assumes as if there is no interrelationship among sectors in the economy. In addition, unlike the scope of the aforementioned studies which were confined to the impact only on the agricultural sector, it is generally known that the impact of climate change does not give way by just affecting the agricultural sector alone (World Bank, 2006). Hence, it would be more meaningful and realistic to fill the gap by investigating the economy-wide effects of climate change in a general equilibrium setting with a focus on the Ethiopian economy.

It is from the above particulars this study picks up and hence tries to investigate the potential economy-wide impacts of climate change (measured in terms of change in temperature and precipitation pattern) on the Ethiopian economy and how it is distributed across its different AEZs (because different policies may be adopted across agro-ecologies). Moreover, it examines how climate change affects sectoral activities and the composition of trade. Finally, it assesses the consequential impacts on income and welfare of households.

1.3 Objectives of the Study

This study utilizes a computable general equilibrium (CGE) model of the Ethiopian economy to investigate the short-run economy-wide implications of climate change induced crop productivity damages in the country.

Specifically, the paper evaluates the impact of climate change on:

- key macroeconomic indicators,
- sectoral activities and the composition of trade, and
- household livelihoods (measured in terms of real income and welfare).

1.4 Significance of the Study

In addition to its global nature, it is now widely recognized that climate change will have a large effect on economic outcomes, but precisely how much is uncertain. As a result, quantifying the economy-wide impacts of climate change will help the country to formulate effective policies, take adequate mitigation and adaptation actions and ensure genuine participation in global climate change agreements. Moreover, the existing literature on the impact of climate change analyzed using CGE model contains a few studies in Africa and, in fact, in Ethiopia to date. Accordingly, it adds another study that includes a general equilibrium analysis of the impact of climate change.

1.5 Scope and Limitation of the Study

This study assesses the short-run economic implications of climate change induced crop productivity damages in Ethiopia. However, this study does have some limitations. The important limitation is that it entirely relies on changes in temperature and precipitation pattern as proxies for climate change. Consequently, it is imperative for future studies to take other proxies (like CO_2 fertilization effects and climate variability) for climate change impact studies. In addition, similar crop productivity damages are introduced in this study for all types of crops. Hence, there still lies a need to impose different crop productivity damages for different crops. Even though this study does have the above problems, it can still suggest important conclusions regarding the economy-wide impacts of climate change in the country.

1.6 Organization of the Paper

The rest of the paper is organized as follows: Chapter two presents an overview of the Ethiopian economy and environmental condition, while chapter three provides the theoretical and empirical related literature to the study. Chapter four outlines the general equilibrium model and presents the social accounting matrix (SAM) used in this study. Chapter five shows the results of the impact of climate change and chapter six concludes and suggests some implications.

CHAPTER TWO

OVERVIEW OF ETHIOPIAN ECONOMY AND ENVIRONMENTAL CONDITION

2.1 Overview of Ethiopian Economy

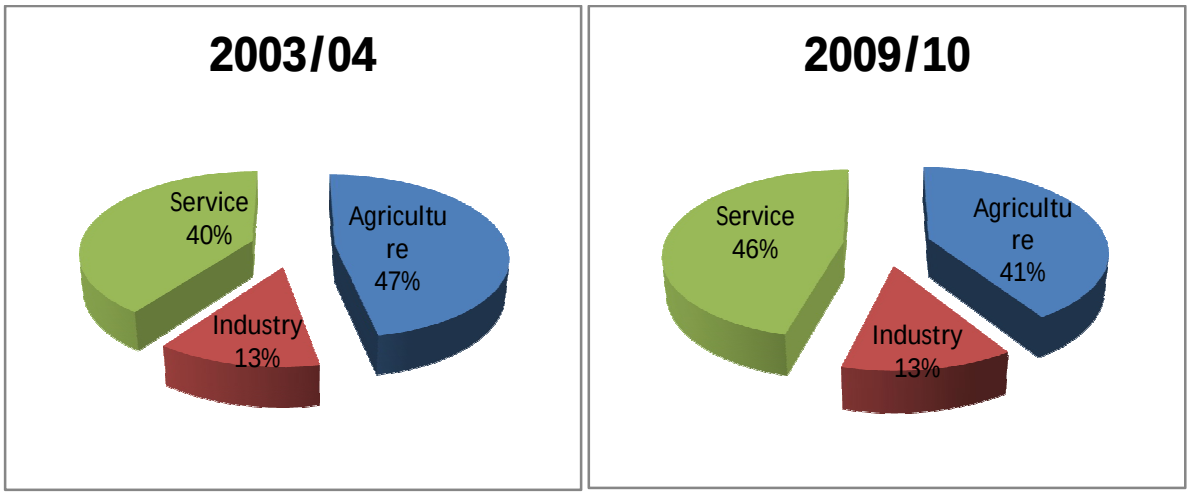
Although Ethiopia is among the poorest nations of the world (UNDP, 2009), it has experienced rapid economic growth in recent years (Dorosh and Thurlow, 2009; MoFED, 2010a). On average, the real GDP has been growing by around 11% in the period 2005/06 - 2009/10. This growth is complemented by the average growth rates of 8%, 10% and 14.6% achieved by agriculture, industry and service sectors respectively. The overall real GDP growth in comparison with an average population growth rate of 2.6% therefore implies that the average annual per capita income has been increasing at a rate of 8.4% (MoFED, 2010a).

The other human development measures have also shown improvements over time owning to improved economic performance. However, they still remained very low as compared to other countries in the world. This is due to the fact that the country is characterized by low per capita income of only 170 USD, overall adult literacy rate of only 36% and there still exists a very high infant and maternal mortality rates (MoRAD, 2010). In addition, life expectancy at birth is only 54.7 years and the overall HDI is among the lowest in the world (UNDP, 2009).

The remarkable growth that has been achieved in recent years was not free of challenges. Some of these challenges which require special mention include low levels of income and savings, low agricultural productivity, limited implementation capacity, unemployment and a narrow modern industrial sector base. Besides the aforementioned challenges, the growth efforts have also been threatened by the twin challenges of inflation, which is mainly attributed to food prices, and the pressure on the balance of payments (MoFED, 2010b). Furthermore, whether induced challenges like climate change has been a major threat to the economy (World Bank, 2006; World Bank, 2008; MoFED, 2010b). These factors coupled with the global financial and economic crisis are seen as the reasons that had and will continue to have a dampening effect on the country`s economic growth (MoFED, 2010b).

In terms of the structure of the economy, the contribution of agriculture to the overall GDP has declined from 47% in the year 2003/04 to 41% in 2009/10 while the contribution of the industry has been stable (Figure 2.1). However, the service sector, for the first time in history, has overtaken agriculture as the largest segment of Ethiopian economy in 2008/2009. Its share increases from 39.7% in 2003/04 to 46% in 2009/10 (MoFED, 2009; MoFED, 2010a). The slow but consistent growth of the service sector is mainly attributed to the growth in real estate, renting and related business activities. Wholesale and retail trade, hotels and restaurants, and banking have also been the other key growth areas in the sector (Access Capital, 2010).

Figure 2.1: Sectoral distribution of real GDP in 2003/2004 compared to 2009/10



Source: MoFED.

The industrial sector in the country is still at its infancy level contributing a very small portion to the national GDP. Not only its share in the country`s GDP but also its contribution to GDP growth has been stagnant centered around 13% and 1.3%, respectively, in the period 2002/03 to 2008/09 (NBE, 2009; MoFED, 2009). Though small, the sector`s growth in recent years is mainly attributed to the expansion in electricity and water, owning to huge investments in the hydroelectric power generation and expansion activities, mining and construction sub-sectors, for instance, which rose by 5.7%, 12.8% and 11.7%, respectively, in the year 2008/09 (NBE, 2009).

Majority of the population in the country obtain their livelihood directly or indirectly from agricultural production. Growth in the economy has been a direct reflection of the performance and growth paths in the sector (NBE, 2009; PANE, 2009). So far the growth strategies of the country gave due attention to agricultural growth. A Plan for

Accelerated and Sustained Development to End Poverty (PASDEP) which covers 2005/06-2009/10 put much thrust, among others, on rural and agricultural growth to achieve its pillar strategies (MoFED, 2007).

The new Growth and Transformation Plan (GTP) 2010/11-2014/15[1] of the country, which is prepared based on PASDEP experiences and achievements, still aims at maintaining agriculture as a major source of growth in order to attain a rapid and broad-based economic growth. The plan explicitly indicates that it is imperative to achieve accelerated and sustained agricultural growth in the next five-years so that it will be possible to reduce poverty and pave the groundwork for the attainment of the Millennium Development Goals (MDGs) by 2015(MoFED, 2010a).

The agricultural sector being rain-fed is, however, sensitive to changes in temperature and precipitation patterns (World Bank, 2006; World Bank, 2008; Deressa, 2010). On the other hand, the sector is the government`s top priority which will determine the country`s economic fate (MoFED, 2010a). In addition, there is strong inter-linkage between agriculture and the other sectors (NBE, 2009, PANE, 2009). Taken as a whole, any weather induced change could seriously affect the country`s economy through its effect on agriculture.

[1] The GTP hinges on seven pillar strategies in order to attain a rapid and broad-based economic growth in the country. Maintaining agriculture as a major source of economic growth is one of its pillar strategies. The others are: sustaining faster and equitable economic growth, creating favorable conditions for the industry to play a key role in the economy, enhancing expansion and quality of infrastructure development, enhancing expansion and quality of social development, building capacity and deepen good governance, promoting women and youth empowerment and equitable benefit (MoFED, 2010a).

2.2 Overview of Environmental Condition in Ethiopia

2.2.1 Environmental Problems in Ethiopia

Environmental problem/stress is now among the major problems which can have significant ecological, social and economic impacts in Ethiopia. The country`s underdevelopment, in one way or another, is linked to the changes in its natural and environmental conditions. As a result, according to MoFED (2010b), it has been widely acknowledged recently that addressing such problems does have several important, poverty reduction, equality and human rights dimensions. Hence, it has become a key issue in the development agenda of the nation (MoFED, 2007; MoFED, 2010).

According to NMA (2007) and MoFED (2007), land degradation, soil erosion, deforestation, loss of biodiversity, water and air pollution, and climate change including desertification, recurrent drought, and floods are the major environmental problems in the country. These problems, among others, have been the major source of risk and vulnerability in most parts of the country (NMA, 2007). Of the total area, 70% of the country is dry sub-humid, semi-arid and arid, which is vulnerable to desertification and drought (MoFED, 2007). Even the humid part of the country is prone to land degradation due to the country's mountainous topography. Furthermore, the increase in livestock and human population and the associated socio-economic activities are all threatening the country`s biodiversity (World Bank, 2006; NMA, 2007).

The history of drought in Ethiopia is as old as the country itself (Molla, 2008; World Bank, 2006). It has been traced as far back as 250 B.C (World Bank, 2006). Furthermore,

the frequency of droughts has been very severe. For instance, Molla (2008) explained that there were about 177 drought incidences from the first century A.D. up to 1500 A.D. and around 69 drought events between 1500 A.D. and 1950 in the country and it has been affecting the population from time to time (Molla, 2008).[2] In addition, famine and, recently, flood are the main problems that affect millions of people in the country almost every year. Even though the deterioration of the natural environment due to unchecked human activities and poverty has further worsened the situation, the causes of most of the disasters in the country are climate related (NMA, 2007).

2.2.2 Climate Systems in Ethiopia

Climate in Ethiopia is highly controlled by the seasonal migration of the Intertropical Convergence Zone (ITCZ), which follows the position of the sun relative to the earth and the associated atmospheric circulation. Furthermore, it is also highly influenced by the country`s complex topography (NMSA, 2001)

According to Yohannes (2003) the traditional, the Köppen's, the Throthwaite's, the rainfall regimes, and the agroclimatic zone classification systems are the different ways of classifying the climatic systems of the country (Yohannes, 2003). However, the traditional and agro-ecological classifications are the most common ones (Deressa, 2010). The traditional classification, based on altitude and temperature, shows the

[2] Details on the chronology of Ethiopian drought and famine since 1895, the affected areas and its severity are all explained in World Bank (2006).

presence of 5 climatic zones (NMA, 2007). Table 2.1 presents the physical characteristics of agroclimatic zones.

Table 2.1: Traditional Agroclimatic Zones and their Physical Characteristics

Zone	**Altitude (meters)**	**Rainfall (mm/year)**	**Length of Growing Period (days)**	**Average annual temperature(^{o}C)**
Wurch (upper highlands)	3200 plus	900 – 2200	211 - 365	< 11.5
Dega (highlands)	2,300 – 3,200	900 – 1,200	121 - 210	17.5/16 –11.5
Weyna Dega (midlands)	1,500 – 2,300	800 – 1,200	91 - 120	20.0 –17.5/16
Kola (lowlands)	500 – 1,500	200 – 800	46 - 90	27.5 – 20
Berha (desert)	under 500	under 200	0 - 45	>27.5

Source: MoA (2000).

Alternatively, the agro-ecological zone (AEZ) classification system combining growing periods with temperature and moisture regimes put 18 major AEZs which are further sub-divided into 49 AEZs. According to MoA (2000), these AEZs can be grouped into 6 major categories which include the following:

- Arid zone: This zone is less productive and pastoral and occupies 53.5 million hectares of land (31.5% of the country).
- Semi-arid: This agro-ecology is less harsh and occupies 4 million hectares of land (3.5 % of the country).
- Sub-moist: occupies 22.2 million hectares of land (19.7% of the country), highly threatened by erosion.

- Moist: This zone covers 28 million hectares of land (25% of the country) of the most important agricultural land of the country where cereals are the dominant crops.
- Sub-humid and humid: These zones cover 17.5 million hectares of land (15.5% of the country) and 4.4 million hectares (4% of the country), respectively. They provide the most stable and ideal conditions for annual and perennial crops and are home to the remaining forest and wildlife, having the most biological diversity.
- Per-humid: This agro-ecology covers about 1 million hectares of land (close to 1 % of the country) and is suited for perennial crops and forests.

Besides the aforementioned classification methods, the 2005/06 Ethiopian SAM, which is produced by EDRI, distinguished 5 AEZs which mainly differ depending on their climate, moisture regime and land use. This study mainly relies on this classification since the SAM for the country is constructed using this classification. These AEZs are: Humid Lowlands Moisture Reliable; Moisture Sufficient Highlands – Cereals Based; Moisture Sufficient Highlands – *Enset* Based; Drought-Prone (Highlands); and Pastoralist (Arid Lowland Plains) (EDRI, 2009a).

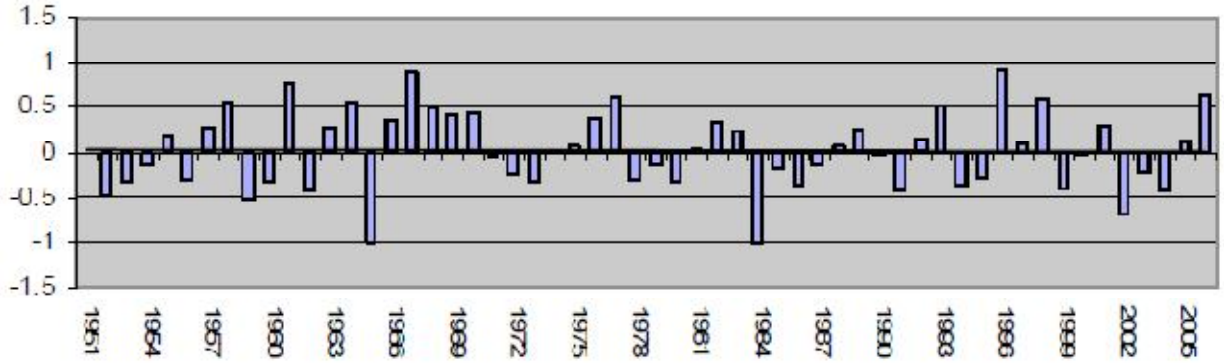
Climate conditions differ extensively across these AEZs. Mean annual rainfall ranges from about 2000 millimeters over some pocket areas in the southwest to less than 250 millimeters over the Afar lowlands in the northeast and Ogaden in the southeast (Deressa, 2010; NMSA, 2001). While mean annual temperature ranges from 10^0C over

the high table lands of northwest, central and southeast to about 35^0C on the north-eastern edges (Deressa 2010; NMA, 2007).

2.2.3 Climate Variability and Observed Trends in Ethiopia

As explained in NMA (2007), baseline climate that was developed using historical data of temperature and precipitation from 1971- 2000 for selected stations in Ethiopia showed a very high year-to-year variation in rainfall for the period 1951 to 2005 over the country expressed in terms of normalized rainfall (see figure 2.1). Over those periods (1951-2000), some of the years have been dry resulting in droughts and famine while others were characterized by wet conditions (NMA, 2007). During extreme drought conditions, it is common that many farmers in the country either die due to hunger or depend on foreign food aid to sustain their lives (Deressa *et al*., 2010). The observed trend in annual rainfall, however, remained more or less constant when averaged over the whole country (NMA, 2007).

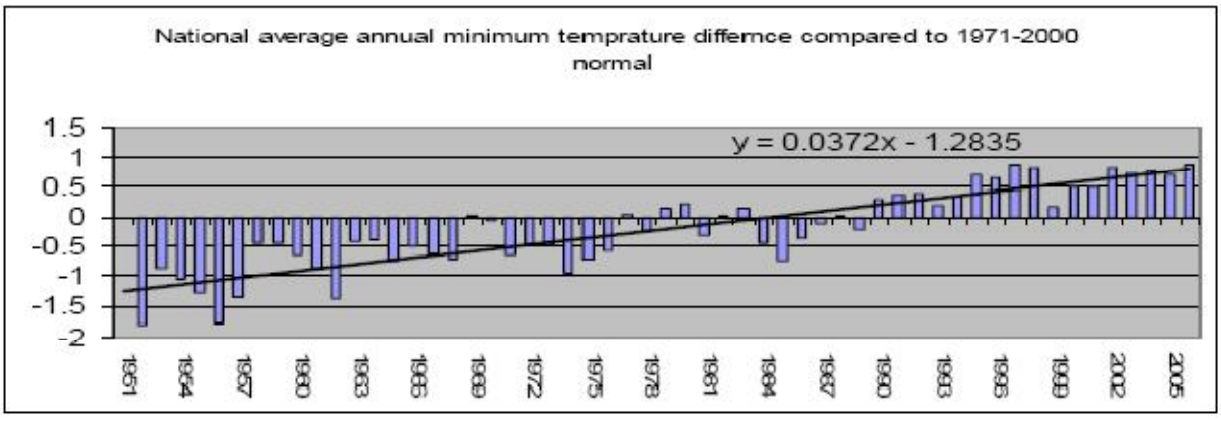
Figure 2.2: Year to Year Variability of Annual Rainfall and trend over Ethiopia expressed in Normalized Deviation (compared to 1971-2000 normal)



Source: NMA (2007).

Studies also indicate that there has been a very high temperature variation and change in its trend over time. Annual minimum temperatures for the period 1951 to 2005 expressed in terms of temperature differences from the mean and averaged over 40 stations showed a very high variability (NMA, 2007). The country experienced both warm and cool years over those 55 years even though the recent years are generally warmest compared to the early periods (Figure 2.2). Moreover, there has been a warming trend in the annual minimum temperature from 1951 to 2005. It has been increasing by about 0.37^{0}C every 10 years (NMA, 2007).

Figure 2.3: Year to Year Variability of Annual minimum Temperature over Ethiopia expressed in temperature difference



Source: NMA (2007)

2.2.4 Projected Climate over Ethiopia

All models predicting future climate change scenario in Ethiopia put similar conclusion in the sense that temperature would increase over a period of time. However, they give conflicting results concerning the predicted level of precipitation- constant, decreasing and increasing level of projected precipitation level is generated using different models.

According to NMA (2007) forecast, the country will experience an increasing level of temperature and precipitation in the coming decades. Using the software MAGICC/SCENGEN (Model for the Assessment of Greenhouse-gas Induced Climate Change)/ (Regional and global Climate SCENario GENerator) coupled model (Version 4.1) for three periods centered around the years 2030, 2050 and 2080, NMA (2007) generated that the mean annual temperature will increase in the range of 0.9-1.1°C by 2030, in the range of 1.7-2.1°C by 2050 and in the range of 2.7-3.4°C by 2080 over Ethiopia for the IPCC mid range emission scenario compared to the 1961-1990 normal. Furthermore, it states that a small increase in precipitation can be expected (NMA, 2007).

Strzepek and McCluskey (2007) using five climate prediction models; Coupled Global Climate Model (CGCM2), the Hadley Centre Coupled Model (HadCM3), ECHAM, CSIRO2 and the Parallel Climate Model (PCM); based on two scenarios (i.e., A2 and B2[3]) from the IPCC Special Report on Emission Scenarios (SRES) showed that temperature will increase in the coming decades in all of the models (Appendix 2). However, precipitation might increase, decrease or become constant depending on the models used (Strzepek and McCluskey, 2007).

[3] A2 emission scenario describes a very heterogeneous world. Economic development is primarily regionally oriented and per capita economic growth and technological change more fragmented and slower than other storylines and scenarios, while B2 describes a world in which the emphasis is on local solutions to economic, social and environmental sustainability (IPCC, 2007b). For detail information on the six scenarios and their description, see the Fourth Assessment Report of IPCC.

CHAPTER THREE

REVIEW OF RELATED LITERATURE

In this chapter, a theoretical link between climate change and agricultural production is established first. Second, the different economic models used to assess the likely impact of climate change on agricultural productivity and thereby the economy is presented. Finally, the chapter concludes by providing empirical literature reviews on the potential economic impacts of climate change from different corners of the world, with a special focus on Africa.

3.1 Climate Change and Agricultural Production

There is a strong and two way interrelationships between climate change and agriculture. The first line is concerned with the contribution of agriculture to the total GHG emissions and hence climate change. The second line is how climate change explains agricultural outputs (Egnonto and Madou, 2008). This study is devoted to the latter side of explanation. Climate change can affect agricultural production in a variety of ways. Temperature and precipitation patterns, extreme climate conditions, surface water runoff, soil moisture and CO_2 concentration are some of the variables which can considerably affect agricultural development (IPCC, 2007; Zhai and Zhuang, 2009).

Most studies concluded that the relationship between climate change and agricultural production is not simply linear (such as Mendelsohn *et al*., 1994; Kabubo-Mariara and Karanja, 2006; Kurukulasuriya and Mendelsohn, 2008). There is usually a certain level

of threshold beyond which the sector may be adversely affected. For instance, IPCC reports that warming of more than 3ºC would have negative impacts on crop productivity globally. However, there is a marked difference regionally with regard to the threshold level. For instance, the potential for crop productivity is likely to increase slightly at mid to high latitudes for local mean temperature increases of up to 1-3^{0}C. On the contrary, low-latitudes will experience losses in crop productivity for even small local temperature increases of 1-2^{0}C (IPCC, 2007b).

The changes in precipitation and temperature can directly influence crop production. Moreover, they might alter the distribution of agro-ecological zones. Precipitation patterns determine the availability of freshwater and the level of soil moisture, which are critical inputs for crop growth. Moderate precipitation may reduce the yield gap between rain-fed and irrigated agriculture by reducing crop variability (Calzadilla *et al.,* 2009). However, heavy precipitation is very likely to result in soil erosion and difficulty to cultivate land due to water logging of soils. Taken as a whole, it will adversely affect crop production (IPCC, 2007b).

Temperature and soil moisture determine the length of growing period and the crop`s development and water requirements. In summary, higher temperature will shorten the freeze periods, promoting cultivation in marginal croplands. However, in arid and semi-arid areas higher temperature will short the crop cycle and reduce crop yields (IPCC, 2007b). In addition, the ecological changes brought on by warming such as the pattern of pests and diseases will depress agricultural production (Zhai and Zhuang,

2009). Globally, temperature increases of up 2^0C may have positive impacts on pasture and livestock productivity in humid temperate regions. However, it will reduce livestock production in arid and semi-arid regions (IPCC, 2007b).

Crop production will be depressed by increased climate variability and increased intensity and frequency of extreme weather events such as drought and floods (IPCC, 2007b; Zhai and Zhuang, 2009; Calzadilla *et al.,* 2009). Its negative impact is much higher in areas where rain-fed agriculture dominates. For instance, frequent droughts not only reduce water supplies but also increase the amount of water needed for plant transpiration. These events will also increase diseases and mortality of livestock which results in production losses (IPCC, 2007b; Zhai and Zhuang, 2009).

Elevated CO_2 concentration alone does have a positive impact on crop (plant) production by stimulating plant photosynthesis and water use efficiency- the amount of water required to produce a unit of biomass or yield. This carbon fertilization effect may favor plants under C3 pathway[4], such as wheat, rice, soya bean, fine grains, legumes, and most trees, which have a lower rate of photosynthetic efficiency, over C4 plants, such as maize, millet, sorghum, sugarcane, and many grasses (IPCC, 2007b; Cline, 2007; Matarira, 2008; Zhai and Zhuang, 2009). In this respect IPCC predicts 10-25% yield increases for C3 crops and 0-10% for C4 crops when atmospheric CO_2 concentration levels reach 550 parts per million. However, changes in temperature and precipitation may limit these effects (IPCC, 2007b).

[4] Crops are grouped into two - C3 and C4- depending on the rate of photosynthesis efficiency.

Specifically to Ethiopia, climate change affects agricultural production through shortening of maturity period and then decreasing crop yield, changing livestock feed availability, affecting animal health, growth and reproduction, depressing the quality and quantity of forage crops, changing distribution of diseases, changing decomposition rate, contracting pastoral zones, expansion of tropical dry forests and the disappearance of lower montane wet forests, expansion of desertification, etc (NMA, 2007; PANE, 2009).

In most of African countries, there is a strong association between GDP growth and climate variables like rainfall. This resulted owning to lack of economic diversification and strong dependence on the agricultural sector (Bouzaher *et al.,* 2008). The crux of the matter is that, in Africa, this association is a direct reflection of the very high dependence of agricultural production on climate variables. In Ethiopia, such a relationship is very striking. Agricultural output is highly pronounced even by changes in a single climate variable, i.e., rainfall (PANE, 2009).The same is true for the country's GDP as it heavily relies on agriculture (World Bank, 2006; PANE, 2009).

Rain failure, floods and drought and other changes in the country`s natural and environmental system due to climate change threaten the performance of the economy as a whole and cause severe malnutrition and loss of livelihoods for households mainly in marginal and less productive lands in the country (PANE, 2009). This effect is attributed to the fact that those changes can seriously depress agricultural production in the country. This clearly demonstrates that economic growth in general and

households` welfare in particular are still significantly influenced by changes in rainfall and other climate variables (World Bank, 2006).

In conclusion, the impact of climate change in the country can be felt not only on agricultural output but also on other sectors of the economy, the country's trade patterns, incomes, consumption and welfare of households etc.

3.2 Models to assess the Impact of Climate Change

The efforts to measure the economic impact of climate change is growing. However, little research has focused specifically on the developing nations until 1999 (Mendelsohn and Dinar, 1999). Although more studies dedicated to developing countries have emerged since then, a few national level studies for Ethiopia have been done. Accordingly, little is known about how climate change may affect the country's agriculture and hence the economy. To assess the likely economic impacts of climate change, researchers have perused either partial equilibrium or general equilibrium approaches (Deressa, 2006; Zhai *et al.,* 2009; Deressa and Hassan, 2009).

Partial equilibrium models are based on the analysis of part of the overall economy such as a single market or subsets of markets or sectors - assuming no interrelationship among sectors. However, general equilibrium models are analytical models, which look at the economy as a complete, interdependent system, thereby providing an economy-wide prospective analysis capturing links between all sectors of the economy (Zhai *et al.,* 2009).

3.2.1 Partial Equilibrium Models

Three basic partial equilibrium approaches have been developed to assess the impacts of climate change on agriculture. These are: Crop simulation models, Agro-ecological zone models, and Ricardian models (Mendelsohn and Dinar, 1999; Zhai *et al.,* 2009).

3.2.1.1 Crop Simulation Models

Crop-simulation models also known as agro-economic models draw on controlled experiments where crops are grown in a field or laboratory settings simulating for different possible future climate and CO_2 levels in order to estimate crop yield responses[5] (Zhai *et al.,* 2009; Zhai and Zhuang, 2009). The changes in outcomes are then assigned to the differences in the variables of interest such as temperature, precipitation, and CO_2 levels as other changes in the farming methods are not allowed across experimental conditions. The yields are then entered into economic models that predict aggregate crop outputs, prices, and net revenue (Mendelsohn and Dinar, 1999).

Due to the fact that each crop requires extensive experimentation, almost all of the crop simulation studies so far focused only on the most important crops (mostly grains). Moreover, these models do not include farmers' adaptation to changing climate conditions in the estimates. As a result, they tend to overestimate the damages of climate change to agricultural production (Mendelsohn and Dinar, 1999; Seo and Mendelsohn, 2008). In addition, such experiments are costly and hence a few locations can only be tested. This poses another problem as to the representativeness of

[5] For more information on crop simulation models, see Mendelsohn and Dinar (1999).

experiments to the entire farm sector. Hence in developing nations, where there are only a few experimental sites, the results of these models may not be generalizable (Molla, 2008).

3.2.1.2 Agro-ecological Zone (AEZ) Models

The agro-ecological zone (AEZ) model (also known as crop suitability approach) is used to investigate the suitability of various lands and biophysical attributes for crop production. The initial task in this model is to categorize the existing lands into smaller units, which differ in the length of growing period (defined based on temperature, precipitation, soil characteristics, and topography differences) and climate. This approach analyzes land suitability for crop production by including crop characteristics, existing technology, and soil and climate factors (FAO, 1996). The inclusion of the above variables made the identification and distribution of potential crop producing lands possible. Since climate is included in this model as one of the determinants of land suitability for crop production, it can be used to predict the impact of changing climatic conditions on potential agricultural output and cropping patterns (Molla, 2008).

These models suffer from the same limitation as the crop simulation models in that researchers must explicitly account for farmers' adaptation to changing climate conditions (Mendelsohn and Dinar, 1999). They also make use of a simulation of crop yields (not measured crop yields) in order to assess the potential production capacity of different agro-ecological zones. Moreover, the impossibility to predict final outcomes

without explicitly modeling all the relevant components remains to be the model`s additional problem. Hence, overlooking a single major factor would seriously damage the model's predictions (Mendelsohn and Tiwari, 2000).

3.2.1.3 Ricardian Models

The Ricardian model is a cross-sectional approach developed by Mendelsohn *et al.* (1994) in order to examine the impact of climate change on agriculture in the United States (Mendelsohn *et al.,* 1994; Mendelsohn and Nordhaus, 1996; Deressa *et al.,* 2005). It is named after David Ricardo (1772–1823) because of his original observation that the value of land would reflect its net productivity under perfect competition (Deressa *et al.,* 2005; Mariara and Karanja, 2006; Malua and Lambi, 2007; Kurukulasuriya and Mendelsohn, 2008).

This model has been extensively used to measure the marginal contribution of environmental (and other) factors to farm income (land values) by regressing farm performance (land values or net revenue) on environmental and other socio-economic factors (Mendelsohn *et al.,* 1994; Mendelsohn and Dinar, 1999; Deressa *et al.,* 2005). It is often adopted and used in different countries such as Brazil, India, USA (Mendelsohn and Dinar, 1999; Deressa *et al.,* 2005) and some other African countries like Burkina Faso, Cameroon, Egypt, Ethiopia, Kenya, Senegal, South Africa, Zambia and Zimbabwe (Molla, 2008).

The Ricardian model incorporates farmers' adaptation to changing local climate conditions; an advantage over the above two approaches. Because farmers are risk minimizers, there is every reason to expect that they adapt to climate change by altering the crop mix, planting and harvesting dates, and following a host of agroeconomic practices, among other things (Mendelsohn and Dinar, 1999; Deressa, 2006; Deressa and Hassan, 2009). Moreover, the model makes possible comparative assessment of 'with' and 'without' adaptation scenarios (Mano and Nhemachena, 2006). The other advantage of the model is that it can be used at a lesser cost than the other models as secondary data on cross-sectional sites can be relatively easy to collect on climatic, production and socio-economic factors (Deressa, 2006; Deressa and Hassan, 2009).

However, the Ricardian model is criticized on certain grounds. First, it is not based on a carefully controlled experiment across farms. Farms may differ across space for many reasons in addition to those included in any model. Hence, one cannot guarantee that all of the factors have been taken into account in the analysis; some of them may not even be measured at all (Cline, 1996; Mendelsohn and Dinar, 1999). Second, it also suffers from being a partial equilibrium analysis in the sense that it fails to consider price variations; all farms face the same prices which results in bias in welfare calculations (Mendelsohn and Nordhaus, 1996; Cline, 1996). Finally, it is also weak since it does not take into account carbon fertilization effects; it only uses precipitation and temperature (Cline, 1996; Mendelsohn and Tiwari, 2000).

3.2.2 General Equilibrium Models

Computable general equilibrium models (CGE) are simulations which combine the abstract walrasian general equilibrium structure formalized by Arrow and Debreu with realistic economic data to solve numerically for the levels of supply, demand and price that support equilibrium across a specified set of markets (Peterson, 2003; Wing, 2004). It is "computable" in the sense that an explicit numerical solution for all endogenous variables in the model is computed from equations describing the economy, given numerical values for the parameters and the exogenous variables (Peterson, 2003). Despite their wide economic applications, they are viewed by some economists as a "black-box"- whose results cannot be meaningfully traced to any particular features of their data base or input parameters, algebraic structure, or method of solution (Wing, 2004).

However, climate change directly or indirectly affects different sectors of the economy and hence the complex interactions among the different sectors must be studied in order to assess its impact on agriculture and thereby the whole economy. It is a CGE model which can elucidate such interactions between agriculture and other sectors in an economy- the model's best advantage (Zhai et al., 2009). In addition, its theoretical consistency and the presence of considerable scope for altering aggregations are some additional advantages of a CGE model (Peterson, 2003). In order to trace out a more accurate, realistic and consistent pictures of the economic system, this study made use of a CGE model.

3.3 Empirical Literature on the Impact of Climate Change

Zhai and Zhuang (2009) examined the long-run agricultural impact of climate change in the world with special reference to Southeast Asia (Indonesia, Malaysia, Philippines, Singapore, Thailand, and Viet Nam), while the study by Zhai *et al.* (2009) focused on the People's Republic of China (PRC). Based on a dynamic CGE model of the global economy and the Cline's business as usual crop productivity estimates, both studies found that global crop, livestock and processed food production would shrink by 7.4%, 5.9% and 4.6% respectively in the year 2080. The strongest negative impact of climate change on crop output would be in Sub Saharan Africa, Latin America and South Asia which is about 30%, 24% and 20%, respectively. The impact on Southeast Asia would be more moderate, but significant at 17% by 2080. In regions where the impacts on agricultural productivity are small or positive, however, crop production would expand. The highest would be in New Zealand which is by about 141%. This is due to its higher agricultural productivity under climate change and relatively small crop share in its economy. In addition, the study reveals that such cross-region variation also applies for livestock and processed food production.

Zhai and Zhuang (2009) further showed that all of the Southeast Asian countries would see output losses in all crop sectors, except rice output in Malaysia. The highest aggregate crop production loss would be experienced by Singapore and the lowest would be in Viet Nam, by about 48% and 11% respectively. Except for Singapore and Thailand, livestock production would decrease in the other countries. The said study

further showed that the projected slowdown in agricultural productivity further affects the macroeconomic performance of the countries. All the six countries would see contractions in real GDP, ranging from 0.3% in Singapore to 2.4% in Thailand. Moreover, a modest reduction in the levels of investment and consumption would happen.

According to both papers, on average, China's crop output is seen to experience a decline of 0.1%. It is merely Wheat production which would expand (by 4.2%) while the output of others would contract. Zhai *et al.* (2009) showed that China would experience higher exports and fewer imports in crop sector mainly due to the relatively less climate change damage on crop agriculture as compared to the world`s average. The rise in exports ranges from 46.8% for paddy rice to 126.7% for wheat, while the decline in imports ranges from 14.9% to 34.1%. Crop productivity losses are expected to result decline in the outputs of non-crop agriculture, mining, manufacturing and services ranging from 1% to 2% mainly because of rising input costs and resource diversion towards crop agriculture.

Using the Ricardian model and cross-sectional data, Mendelsohn *et al.* (1994) and Seo and Mendelsohn (2008) assessed the impact of climate change on the US and South American agriculture, respectively. Mendelsohn *et al.* (1994) concluded that climate has a complicated effect on agriculture which is highly nonlinear and varying by season. Specifically, the estimated marginal impacts revealed that higher temperatures are likely to reduce while higher precipitation would stimulate average farm values (except

in autumn which would be the reverse). This result is further confirmed by Mano and Nhemachena (2006) on Zimbabwean agriculture, Kabubo-Mariara and Karanja (2006) on crop agriculture in Kenya and Malua and Lambi (2007) on crop farming in Cameroon. However, Seo and Mendelsohn (2008) indicated that both increasing temperature and precipitation would be harmful on South American agriculture even though climate sensitivity varies across farm types (i.e. Crop only, mixed and livestock-only farms).

Some studies investigated the impact of uniform climate scenarios on agriculture. For instance, Mano and Nhemachena (2006) indicated that the uniform scenarios of increasing temperature by 2.5^0C and 5^0C and decreasing precipitation by 7% and 14% results in contraction in net farm revenues across all farms in Zimbabwe. Similarly, Malua and Lambi (2007) found that the uniform scenarios of increasing temperature by 2.5^0C and 5^0C would cause a fall in crop net revenues by $0.65 and $1.82 billion, respectively, in Cameroon. In addition, they indicated that the uniform scenarios of decreasing precipitation by 7% and 14% would result a decline in crop net revenues by $2.95 and $4.96 billion, respectively.

Based on CO_2 doubling scenario, which predicts a 5^0F and 8% increase in temperature and precipitation, respectively, Mendelsohn *et al.* (1994) estimated the annual agricultural damage in the US to be in the neighborhood of 4-5% using the crop land model. However, it would be slightly beneficial using crop-revenue approach (by around 1% annually). Similarly, Seo and Mendelsohn (2008) assessed the impact of

projected climate from CCC and PCM models on South American agriculture. In so doing, PCM scenarios predicted a loss of 23% and 13% of land value in the crop-only and mixed farms, respectively, by the year 2100. Contrarily, livestock-only farms would experience a boost in their incomes by 38%. However using predicted climate from the CCC model, they estimated a much larger decline in incomes of all the farm types. Mano and Nhemachena (2006) also examined the impact of three SRES climate change scenarios, namely CGM2, HadCM3 and PCM on agriculture in Zimbabwe. They indicated that farm net revenues would decline, respectively, by US$0.8 billion, US$1.3 billion and US$1.4 billion across all farms as of 2100. The study by Kabubo-Mariara and Karanja (2006) used climate scenarios from CCC and GFDL, which predicts a 3.5°C and 4°C increase in temperature, respectively, while both of them predicts a 20% increase in precipitation by the year 2030 over Kenya. The results predicted a 1% (US$3.54 per hectare) gain in high potential zones but a 21.5% (US$54 per hectare) loss in medium and low potential zones for simulations based on CCC model. Using the GFDL model, the result predicted a loss of US$32 per hectare in the high potential zones while the losses would be US$178 per hectare in medium and low potential zones by the year 2030.

Deressa *et al*. (2005) using the Ricardian model assessed the impact of climate change on South African sugarcane production under irrigation and dryland conditions. Utilizing time series data for the period 1977 to 1998, they showed that climate change has a significant effect on net revenue per hectare in sugarcane farming with higher

sensitivity to future increases in temperature than precipitation. This result is similar with the finding of Kabubo-Mariara and Karanja (2006) on Kenyan crop agriculture. In addition, in line with the result of Mendelsohn *et al.* (1994), Deressa *et al*. (2005) revealed that an increase in temperature and precipitation by 2^0C and 7% (doubling of CO_2), respectively, has negative impacts on sugarcane production. This result is further shown to be unevenly distributed across the indicated farming types. However, the difference is negligible as the reduction in net revenue per hectare is about 1% more in dryland farming as compared to irrigated farming. Hence, they concluded as if irrigation is not a very effective adaptation measure to mitigate climate change impacts on sugarcane farming.

The other study by Gbetibouo and Hassan (2004) used the same approach to analyze the economic impact of climate change on major South African field crops. Similar to the finding of Deressa *et al*. (2005) on sugarcane farming, this study concludes that production of field crops in South Africa will be very sensitive to marginal changes in temperature as compared to changes in precipitation. However, unlike Deressa *et al*. (2005), they argues that moving from rain-fed to irrigated agriculture could be an effective adaptation option to reduce the damages of climate change for the field crops. This result is further confirmed by Kurukulasuriya and Mendelsohn (2008) on African cropland using Ricardian model, cross-sectional data from 11 countries in the region, and future climate scenarios from three AOGCMs. In addition, the marginal impacts of Kurukulasuriya and Mendelsohn (2008) suggest that higher temperatures would

increase net revenues from irrigated farms while it would reduce net revenues from dryland farms. However, higher precipitation would stimulate net revenue in both types of farms.

Three different studies in Ethiopia relied on the same approach, i.e., Ricardian model. Deressa (2006) analyzed the impact of climate change on total agricultural production, while Deressa and Hassan (2009) and Molla (2008) assessed the impact on crop agriculture. All of them revealed that climate variables have significant impacts on net revenue per hectare. Deressa (2006) concluded that increasing temperature marginally during the winter and summer seasons reduce net revenue per hectare by US$997.7 and US$177.6, respectively. However, it increases net revenue per hectare by US$337.8 and US$1879.7 in the spring and fall seasons, respectively. Deressa and Hassan (2009), on the other hand, indicated that increasing annual temperature reduces net revenue per hectare by US$ 21.61 (though it is insignificant). However, based on Molla(2008), marginal increase in annual temperature for the model without adaptation will lead to a change in crop net revenue of -3358.41 birr for Nile basin of Ethiopia, 3483.25 birr for irrigated farms (though not significant even at 10% level of significance) and -5904.97 birr for dry land farms. But for the model with adaptation, the change in crop net revenues amount -3127.95 birr, 2275.41 birr (not significant) and -4485.46 birr for Nile basin of Ethiopia, irrigated and dry land farms respectively.

Moreover, Deressa (2006) indicated that increasing precipitation marginally increases net revenue per hectare by US$225.1 in the spring season, while it reduces net revenue

per hectare by US$464.7, US$18.9 and US$64.2 in the winter, summer and fall seasons, although the last two are insignificant. According to Deressa and Hassan (2009), however, the marginal impact of increasing annual precipitation reduces net revenue per hectare by US$322.75. Molla (2008), on the other hand, showed that it will increase crop net revenues by 322.89 birr, 309.54 birr and 352.68 birr for the model without adaptation while for the model with adaptation the gain amounts 147.45 birr, 147.46 birr and 267.66 birr for Nile basin of Ethiopia, irrigated and dry land farms, respectively.

Deressa (2006) and Molla (2008) further revealed that the uniform scenarios of increasing temperature by 2.5^{0}C and 5^{0}C and decreasing precipitation by 7% and 14% are all damaging to agriculture in the country, except Molla(2008) indicated that increasing temperature by 2.5^{0}C results in net gain for the irrigated farms.. Moreover, using the forecasted values of temperature and precipitation from three climate change models (i.e. CGM2, HaDCM3 and PCM), Deressa (2006) predicted that net revenue per hectare would increase by 2050, while it would decrease by 2100, while Deressa and Hassan (2009) forecasted reduced crop net revenue per hectares both in the year 2050 and 2100. This study further revealed that the impact of climate change would worsen over time unless it is abated using prudent adaptation actions.

3.4 Summary of the Literature

This chapter described the ways through which climate change can affect agricultural production, the class of methodologies used to carry out climate change impact studies and the empirical literature related to the topic. According to the literature, temperature

and precipitation patterns, extreme climate conditions like floods and drought, surface water runoff, soil moisture and CO_2 concentration are some of the important climate variables which can substantially affect agricultural production. It has been further assessed that Ethiopia is not an exception to be affected by these variables.

The class of approaches used to assess the impact of climate change can be broadly classified as partial and general equilibrium models. Partial equilibrium models include crop-simulation, AEZ and Ricardian models. Even though CGE models are criticized as being a “black –box”, it has been indicated that such models do have the added advantage of explaining the interactions among the economic sectors and will provide more accurate, realistic and consistent pictures of the economic systems.

The impact of climate change on agriculture is indicated to be highly complicated. Some countries (or regions) might benefit as a result of warming, whereas others may lose in terms of agricultural production. The impact may not even be uniformly distributed within a nation if it has different AEZs or farming methods. In addition, some of the studies revealed that adaptation (like irrigation) may reduce the harmful effects of climate change. In Ethiopia, most of the studies concluded that increasing temperature and decreasing precipitation are damaging to agriculture. All of the studies, however, focused only on the impact on agriculture and they made use of a partial equilibrium analysis which assumes that there is no interrelationship among sectors. Consequently, there lies a need to investigate the economy-wide impacts of climate change in the country.

CHAPTER FOUR

METHODOLOGY AND DATA

4.1 The Model

In order to analyze the potential economic impacts of climate change in Ethiopia, this study made use of a CGE model. A CGE model is employed mainly because it overcomes the downsides of partial equilibrium models. The focus of this study is the impact effects, not the long-run effect of climate change and hence it can be well addressed by using a static CGE model.

The model used in this study is the standard CGE model developed by International Food Policy Research Institute (IFPRI) (Lofgren *et al*., 2002), which follows the neoclassical-structuralist modeling tradition originally presented in Dervis *et al*. (1982) with some additional features being included.[6] Most of the theoretical description of the static model, therefore, follows from Lofgren *et al*. (2002), unless otherwise stated. Some major equations are presented along with the description while all of them are included in the appendix section. The main features of the model consist of four blocks: prices, production and trade, institutions, and system constraints. Finally, the closure rules adopted in this particular study are discussed along with system constraints block.

[6] The additional features included in the IFPRI`s standard CGE model are: household consumption of non-marketed (home) commodities, transaction costs for commodities that enter the market sphere and a separation between production activities and commodities.

4.1.1 Prices

The import price in local currency units (LCU) paid by domestic users is a transformation of the world price of imported goods, considering the exchange rate and import tariffs plus transaction costs per unit of the import (Eq. 1)[7], while the export price in LCU is the price received by domestic producers when they sell their output in export markets (Eq. 2).

$$PM_c = pwm_c \cdot (1 + tm_c) \cdot EXR + \sum_{c' \in CT} PQ_{c'} \cdot icm_{c'c} \qquad c \in CM \text{ [8]} \quad \ldots\ldots (1)$$

$$PE_c = pwe_c \cdot (1 - te_c) \cdot EXR - \sum_{c' \in CT} PQ_{c'} \cdot ice_{c'c} \qquad c \in CE \quad \ldots\ldots (2)$$

Where PM_c is import price in LCU, pwm_c is import price in FCU, tm_c is import tariff, EXR is exchange rate, te_c is export tax, PQ_c is composite commodity price, $icm_{c`c}$ is quantity of commodity c` as trade input per imported unit of c, PE_c is export price in LCU, pwe_c is export price in FCU, and $ice_{c`c}$ is quantity of commodity *c`* as trade input per exported unit of *c*.

In addition, the model also includes distinct prices for domestic outputs that are used domestically. The marketed output value of domestic commodities at producer prices is therefore defined to be the sum of the values of domestic sales and exports. The gross revenue per activity unit, the activity price, is defined as yields per activity unit multiplied by activity-specific commodity specific prices (Eq. 3).

[7] In this chapter, equation numbers are solely used to facilitate the discussion and some of the numbers may not totally correspond to the equation numbers indicated in the appendix section.
[8] The definition of sets can be found in appendix 1.

$$PA_a = \sum_{c \in C} PXAC_{ac} . \theta_{ac} \qquad a \in A \quad \ldots\ldots (3)$$

Where PA_a is activity price, $PXAC_{ac}$ producer price of commodity c for activity a, and θ_{ac} is yield of output c per unit of activity *a*.

The activity-specific aggregate intermediate input price shows the cost of disaggregated intermediate inputs per unit of aggregate intermediate input (Eq. 4).

$$PINTA_a = \sum_{c \in C} PQ_c . ica_{ca} \qquad a \in A \quad \ldots\ldots (4)$$

Where $PINTA_a$ is aggregate intermediate input price for activity a*,* and ica_{ca} is quantity of *c* per unit of aggregate intermediate input *a.*

Since the total revenue net of taxes of each activity (Eq. 5) is totally used to pay for value-added and intermediate inputs, the following equation implicitly defines the value-added price.

$$PA_a(1-ta_a).QA_a = PVA_a.QVA_a + PINTA_a.QINTA_a \qquad a \in A \quad \ldots\ldots (5)$$

Where QA_a is level of activity, ta_a is tax rate for activity, PVA_a is price of (aggregate) value-added, QVA_a is quantity of (aggregate) value-added, and $QINTA_a$ is quantity of aggregate intermediate input.

4.1.2 Production and trade

Production: In the production side, each producer is assumed to maximize profits subject to production technology in a competitive market (Lofgren *et al.*, 2002; Decaluwé *et al*., 2009). In this study a nested structure for production is adopted. At the top level,

the technology combines the quantities of value-added and total intermediate consumption in fixed shares. In other words, the two composite commodities are assumed to be strictly complementary following a Leontief production function (Decaluwé *et al*., 2009). Hence, the Leontief technology demand for aggregate value–added and intermediate inputs are specified below in equation 6 and 7 respectively.

$$QVA_a = iva_a \cdot QA_a \qquad a \in ALEO \quad \ldots\ldots (6)$$

$$QINTA_a = inta_a \cdot QA_a \qquad a \in ALEO \quad \ldots\ldots (7)$$

Where iva_a is quantity of value-added per activity unit and $inta_a$ is quantity of aggregate intermediate input per activity unit. These parameters measure the shares of the respective composite input per activity unit.

At the bottom level, value-added is represented by a constant elasticity of substitution (CES) function of primary factors (Eq. 8). This implies that there is imperfect substitutability among available factors. Profit maximization implies that producers employ additional factors until the value marginal product of each factor is equal to its price (wage rate for labor and rental rate for capital). Intermediate consumption, on the other hand, is made up of various goods and services which are assumed to be perfectly complementary inputs, and hence it follows a Leontief production function (Eq. 9) (Lofgren *et al.*, 2002).

$$QVA_a = \alpha_a^{va} \cdot \left(\sum_{f \in F} \delta_{fa}^{va} \cdot QF_{fa}^{-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} \qquad a \in A \quad \ldots\ldots (8)$$

$$QINT_{c\alpha} = ica_{c\alpha}.QINTA_{\alpha} \qquad a \in A; c \in C \quad \text{..... (9)}$$

Where $\alpha_{\alpha}^{\upsilon\alpha}$ is efficiency parameter in the CES value-added function which measures total factor productivity, $\delta_{f\alpha}^{\upsilon\alpha}$ is CES value-added function share parameter for factor f in activity a, $QF_{f\alpha}$ is quantity demanded of factor f from activity a, $\rho_a^{\upsilon\alpha}$ is CES value-added function exponent, and $QINT_{c\alpha}$ is quantity of commodity *c* as intermediate input to activity *a*.

Factor demand equations (from Eq. 8) can be obtained by equating the marginal cost of each factor with the marginal revenue product of the factor (cost minimization subject to the technology).

International Trade: On the demand side, imperfect substitutability between imports and domestic outputs is assumed in the model (Eq. 10). This geographical differentiation is introduced by the standard "Armington" assumption with a constant elasticity of substitution (CES) function between imports and domestic goods (Lofgren *et al.*, 2002; Annabi *et al.*, 2004).

$$QQ_c = \alpha_c^q \cdot \left(\delta_c^q \cdot QM_c^{-\rho_c^q} + (1-\delta_c^q) \cdot QD_c^{-\rho_c^q}\right)^{-\frac{1}{\rho_c^q}} \qquad c \in (CM \cap CD) \text{ .... (10)}$$

Where QQ_c is the quantity of goods supplied to domestic market, α_c^q is an Armington function shift parameter, δ_c^q is an Armington function share parameter, ρ_c^q is an Armington function exponent, and QD_c is quantity sold domestically of domestic output.

From cost-minimization subject to the Armington function and a fixed quantity of composite commodity, the optimal mix between import demand and demand for domestic output is given by:

$$\frac{QM_c}{QD_c} = \left(\frac{PDD_c}{PM_c} \cdot \frac{\delta_c^q}{1-\delta_c^q} \right)^{\frac{1}{1+\rho_c^q}} \qquad c \in (CM \cap CD) \quad \ldots\ldots (11)$$

Where PDD_c is the demand price for commodity c produced and sold domestically.

Equation (9) assures that an increase in the domestic-import price ratio generates an increase in the import-domestic demand ratio, i.e., consumers tend to shift away from a relatively expensive commodity (Ferede, 2010). It should be noted, however, that there are commodities which have either imports or domestic sales of domestic output but not both.

On the supply side, producers allocate total domestic production to two alternative destinations: exports and domestic sales. Imperfect transformability between the two destinations is assumed and hence constant elasticity of transformation (CET) function is used (Eq. 12).

$$QX_c = \alpha_c^t \cdot \left(\delta_c^t \cdot QE_c^{\rho_c^t} + (1-\delta_c^t) \cdot QD_c^{\rho_c^t} \right)^{\frac{1}{\rho_c^t}} \qquad c \in (CE \cap CD) \quad \ldots\ldots (12)$$

Where QX_c is aggregate marketed quantity of domestic output of commodity c, α_c^t is a CET function shift parameter, δ_c^t is a CET function share parameter, QE_c is quantity of exports, and ρ_c^t is a CET function exponent.

From the first order conditions of maximization of producer revenue given PE_c and PM_c and subject to the above CET function and a fixed quantity of domestic output, the optimal mix between exports and domestic sales can be expressed as:

$$\frac{QE_c}{QD_c} = \left(\frac{PE_c}{PDS_c} \cdot \frac{1-\delta_c^t}{\delta_c^t} \right)^{\frac{1}{\rho_c^t - 1}} \qquad c \in (CE \cap CD) \quad \ldots\ldots (13)$$

Where PDS_c is the supply price for commodity c produced and sold domestically.

Equation (13) indicates that an increase in the export-domestic price ratio stimulates suppliers towards the export market since it offers relatively a higher price (Ferede, 2010). In conclusion, it should be noted that certain domestic outputs are produced solely for exports or domestic sales, not for both.

4.1.3 Institutions

Institutions of the CGE model are households, enterprises, government and the rest of the world. Total income of each factor is represented by the following equation (Eq. 14), which is divided among domestic institutions in fixed shares after payment of transfers to the rest of the world (Eq. 15).

$$YF_f = \sum_{a \in A} WF_f . \overline{WFDIST}_{fa} . QF_{fa} \qquad f \in F \quad \ldots\ldots (14)$$

$$YIF_{if} = shif_{if} \cdot \left[(1 - tf_f) \cdot YF_f - trnsfr_{rowf} \cdot EXR \right] \qquad i \in INSD \,;\, f \in F \quad \ldots\ldots (15)$$

Where YF_{if} is income of factor *f* ,WF_f is average price of factor, $\overline{WFDIST}_{fa}$ wage distortion factor for factor f in activity a (exogenous variable), YIF_{if} is income to domestic institution *i* from factor *f* , $shif_{if}$ is share of domestic institution *i* in income of factor f , tf_f is direct tax rate for factor f, and $trnsfr_{rowf}$ is transfer from factor *f* to the rest of the world.

Households and enterprises receive income from factors of production (defined by Eq. 15) and transfers from other institutions. Households use their income to pay direct taxes, save, consume, and make transfers to other institutions. Hence, total household consumption spending is defined as the income that remains after direct taxes, savings, and transfers to other domestic nongovernmental institutions (equation 16).

$$EH_h = \left(1 - \sum_{i \in INSDNG} shii_{ih}\right).(1 - MPS_h).(1 - \overline{tins}_h).YI_h \qquad h \in H \quad \ldots\ldots (16)$$

Where EH_h is household consumption expenditure, $shii_{ih}$ is share of net income of a household transferred to institution *i*, MPS_h is marginal propensity to save for households, $\overline{tins}_h$ is direct tax rate for households, and YI_h is income of households.

Household consumption expenditure is derived from the maximization of a Stone-Geary utility function subject to a household budget constraint (Lofgren *et al.*, 2002; Annabi *et al.*, 2004; Decaluwé *et al*., 2009). These expenditure functions are referred to as linear expenditure system (LES) since spending on individual commodities is a linear function of total consumption spending. However, enterprises allocate their income only to direct taxes, savings and transfers to other institutions- they do not consume

commodities. Total government revenue, on the other hand, is derived from (different) taxes, factor incomes, and transfers from the rest of the world. This income is then allocated between consumption and transfers (Eq. 17) (Lofgren *et al.*, 2002).

$$EG = \sum_{c \in C} PQ_c . QG_c + \sum_{i \in INSDNG} trnsfr_{igov} . \overline{CPI} \quad \text{..... (17)}$$

Where: EG is government expenditure, QG_c is government consumption demand for commodity, and $\overline{CPI}$ is consumer price index.

It should be noted that government consumption (QG_c) is defined as the base-year consumption multiplied by an exogenous adjustment factor.

4.1.4 System Constraints and Closure Rules

The model imposes equality between quantity supplied and demanded for each factor and composite commodity. Furthermore, three broad macroeconomic balances are imposed in the model: the current account balance, the government balance and the balance between saving and investment. General equilibrium is, therefore, defined by the above balances. The commodity market clears through prices. However, a number of assumptions, i.e. “closure rules”, are put in place in this study about how the economy maintains the above macroeconomic and factor market equilibriums.

For the current account, a flexible exchange rate is assumed to maintain a fixed level of foreign savings. This closure is appropriate given the floating exchange rate regime in the country. For the government account, tax rates and real government consumption are held constant, leaving the fiscal deficit to adjust to ensure that public expenditure

equals receipts, i.e. government savings are flexible. This closure is preferred since it is assumed that changes in tax rates are politically motivated and thus are adopted independent of changes in other policies or economic environment. For the savings-investment account, a savings-driven closure is adopted, in which the real investment passively adjusts to ensure that savings equals investment spending (cost) in equilibrium.

For the factor market closure, administrative labor, professional labor and land are assumed to be fully employed and mobile across sectors, while skilled labor and capital are assumed to be fully employed and activity specific. The remaining labor categories, i.e. agricultural and unskilled labor are assumed to be unemployed and mobile across sectors. According to Lofgren and Robinson (2004), the CGE model determines only relative prices and a numéraire is needed to anchor the aggregate price level. Hence, the CPI is chosen as numéraire in this particular study such that all changes in nominal prices and incomes in simulations are relative to a fixed CPI.

4.2 The Data

The major dataset used for the CGE analysis is the Ethiopian 2005/2006 SAM constructed by the EDRI. The SAM is disaggregated in such a way that it identifies 69 sub-sectors, 24 of which are in agriculture providing sufficient disaggregation to the focus of this study. The agricultural outputs are classified into three major categories of crops, livestock, and forestry and fishery (table 4.1). Crops in turn fall into five broad groups: cereals, pulses and oilseeds, *enset*, horticulture, and export-oriented crops.

In addition, farm production is disaggregated across four rural agro-ecological zones to account for heterogeneity in cropping patterns that emanate from the differences in climate, moisture regime and land use. These include Zone 1a (humid highland region); Zone 1b (humid lowland region); Zone 2 (drought-prone region); and Zone 3 (pastoralist region).[9]

The SAM further identified 12 household groups. Broadly, they are disaggregated by location, i.e. rural zones, small and big urban centers. Furthermore, they are divided based on poverty status as poor and non-poor households. The rural households are further distinguished based on differences in agro-ecologies. The factors of production in the dataset can broadly be classified into four categories of capital, labor, land and livestock. Labor is disaggregated into skilled, administrative, professional, unskilled, and agricultural labor. Land and livestock are disaggregated by agro-ecological zones and based on poor non poor status of households. Hence, the total number of factors of production equals 22.

[9] The original 2005/06 Ethiopian SAM identifies five agro-ecological zones as described in chapter two. However, in this study the moisture sufficient highland- enset based agro-ecological zone is included in Zone 1a. For a complete presentation of mapping of each of the country's administrative divisions with the stated agro-ecologies, see EDRI (2009a).

Table 4.1: Disaggregation of sectors in the SAM

• Agriculture Cereals 1. *Teff* 2. Barley 3. Wheat 4. Maize 5. Sorghum Pulses and Oilseeds 6. Pulses 7. Oilseeds Horticulture 8. Vegetables 9. Fruits *Enset* *10. Enset* Export-oriented Crops 11. Cotton 12. Sugarcane 13. Leaf Tea 14. Tobacco 15. Coffee 16. Flowers 17. Chat 18. Other Crops Livestock 19. Cattle 20. Milk 21. Poultry 22. Animal products	Other Agriculture 23. Fishing 24. Forestry • Industry Mining 25. Coal 26. Natural gas 27. Other mining Manufacturing Food processing 28. Meat 29. Dairy 30. Vegetable products 31. Grain milling 32. Milling services 33. Sugar refining 34. Tea processing 35. Other foods processing 36. Beverages 37. Tobacco processing Non-processing manufacturing 38. Textiles 39. Yarn 40. Fibers 41. Lint 42. Clothing 43. Leather 44. Wood products	45. Paper and publishing 46. Petroleum 47. Fertilizer 48. Other Chemicals 49. Nonmetal Minerals 50. Metals 51. Metal Products 52. Machinery 53. Vehicles 54. Electrical machinery 55. Other manufacturing Other Industry 56. Electricity 57. Water 58. Construction • Services Private services 59. Trade services 60. Hotels and catering 61. Transport 62. Communications 63. Financial services 64. Business services 65. Real estate 66. Other private services Public services 67. Public Administration 68. Education 69. Health

Source: EDRI (2009b).

CHAPTER FIVE

SIMULATIONS AND RESULTS

5.1 Simulation scenarios

As mentioned when describing the projected climate over Ethiopia, models give controversial results about future climate conditions in the country. Precipitation projections, in most cases, are completely opposite in sign even though temperature projections are more or less similar in terms of direction of magnitudes. There are two ways to look at almost all of the projections. First, most of the models forecasted that both of the climate variables will increase in the coming decades. Second, a few others estimated increasing temperature while precipitation will decrease in the years to come. To see these aspects, this study finds it relevant to carry out two separate simulation scenarios. These scenarios are consistent with the changes in climate conditions from the current levels over Ethiopia that is predicted by CGM2 and PCM models by 2050.[10]

Simulation 1: Increasing temperature and decreasing precipitation by 3.26^0C and 12.02mm, respectively (SIM1).

Simulation 2: Increasing temperature and precipitation by 2.25^0C and 4.06mm, respectively (SIM2).

Because of the above changes in climate conditions, productivity in crop agriculture (cereals, pulses and oilseeds, *enset*, horticulture and export crops) is assumed to be different compared to the case with no climate change. Hence, the crop productivity

[10] See Deressa (2006) or Deressa and Hassan (2009).

shocks that are calculated based on the estimates of Deressa and Hassan (2009) to reflect the effect of climate change are imposed. These shocks indicate crop productivity damages of 9.71%in SIM1 and 15.4% in SIM2. However, due to lack of sector specific estimates of productivity damages, the crop productivity shocks are assumed to be uniform across all crop sectors. To assess the impact of climate change, the results obtained from the crop productivity shocks are compared with the baseline case.

5.2 Results and Discussion

5.2.1 Macroeconomic Impacts

Figure 5.1 presents the simulated impacts of the anticipated climate change induced slowdown in crop productivity on key macroeconomic indicators. Notice that the results of SIM1 and SIM2 represent percentage deviations from the base case. In line with the results of Zhai and Zhung (2009) for the globe in the long run, the figure indicates that real GDP would decline by 3.83% in SIM1 and by 6.07% in SIM2 compared to the initial value as a result of the estimated impacts of climate change on crop productivity. As expected, it revealed that the largest real GDP loss is encountered in the second simulation due to higher damage on crop productivity.

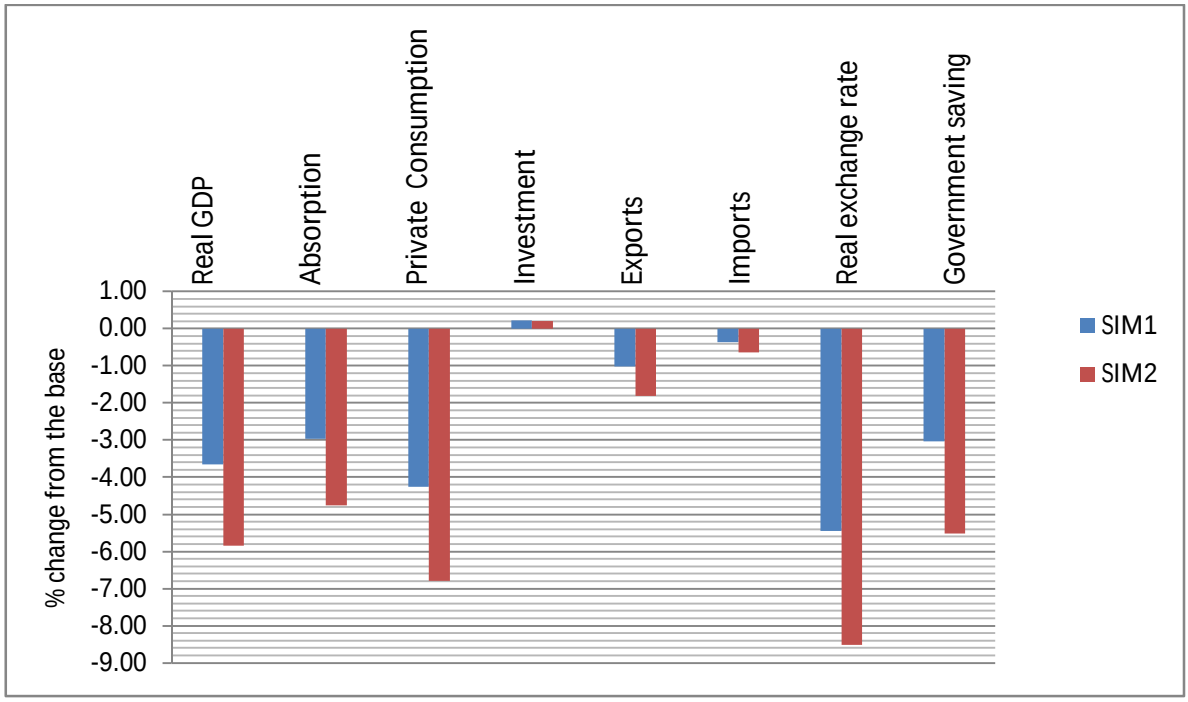
Moreover, it can be seen that absorption, private consumption, exports and imports would decline under all scenarios though the decline is moderate for the latter two indicators. Exports tend to decline mainly because of a significant reduction in domestic production measured in terms of real GDP and imports fall, among others, due to the fall in domestic demand triggered by the decline in incomes. The decline is, however,

higher in exports than imports. This happens in part because of the appreciation of real exchange rate by around 5.44% and 8.50% in SIM1 and SIM2, respectively. Furthermore, government saving also decreases by 3.03% in SIM1 and by 5.5% in SIM2 owning to the increase investments by the government coupled with a 7.97% and 12.36% fall in total government income in SIM1 and SIM2, respectively. Investment is the only macroeconomic variable that could increase in spite of the crop productivity slowdown. This happens due to higher interventions by the government and private stakeholders in order to adopt and mitigate the impact of future climate changes. The increase in investment, however, would become lower with higher productivity declines. It increases by 0.23% in SIM1 and 0.21% in SIM2. This pattern resulted due to significant declines in real incomes of the government and households and the consequential constraints for higher intervention with higher climate change induced crop productivity damages.

The returns for factors are also affected besides the aforementioned macroeconomic indicators. All factors would see reduced returns due to the crop productivity damages. The declines in factor returns are much higher in the second simulation than the first one; actually following the pattern of production in the economy. Factor returns are directly proportional to the level of productivity. Hence, lower productivity as a result of climate change implies lower returns compared to the base case. For instance, the return for capital decreases by 12.46% and 19.16%, and that of agricultural labor falls by 7.22% and 11.5% in the first and second simulations, respectively. For the rest of labor

categories, the decline ranges from 9.51% for the unskilled labor to 13.92% for the skilled labor in SIM1, while in SIM2 it ranges from 14.92% for unskilled labor to 21.49% for the skilled labor. Factor return declines are almost similar across different groups of livestock implying comparable declines in productivity, which is a decline of around 9.38% in the first simulation and 14.67% in the second simulation. However, the declines in land returns differ significantly across different land types owning to significant differences in productivity losses. The lowest decline is in the pastoralist region where land returns are already minimal. This is due to the fact that productivity of land is so low in this region and future changes in climate will no more substantially preclude productivity in this agro-ecology compared to the decline in productivity of land in other agro-ecologies.

Figure 5.1: Major macroeconomic results from the CGE simulations



Source: CGE model simulations

5.2.2 Sectoral Impacts

Table 5.1 reports the simulated sectoral growth results in the country. The decline in real GDP is much more triggered by the shrink in agricultural production of 7.59% in SIM1 and 11.99% in SIM2 compared to the baseline scenario. This is not surprising given that the country's economy is an agrarian economy; accounting for about 48% of real GDP in the baseline scenario. However, the resultant damage on the non-agricultural sector is moderate owning to small input uses from the agricultural output. It contracted only by 0.35% and 0.59% in SIM1 and SIM2, respectively.

The higher decline in the growth of the agricultural sector is witnessed in the cereal crops and pulses and oilseeds sub-sectors. However, it is slightly higher for the latter group of crops. This is attributed to the fact that with changes in climate conditions and the resultant total agricultural productivity declines, farmers tend to follow the food-first approach. Hence, they would allocate much of their resources to cereals production by taking away from the production of cash crops like pulses and oilseeds. This, to some extent, can reduce the impacts on the growth of cereal crops. The damage on the remaining crops, i.e. *enset*, horticultures and export crops is also significant but slightly lower than the impact on cereals and pulses and oil seeds.

The incorporation of crop productivity damages also hampers productivity in the livestock and other agriculture (forestry and fishery) sub-sectors. The contraction is higher in the first sub-sector which is declined by about 1.83% and 2.95% in the first and second simulations, respectively, compared to the base case. However, the other

agriculture sub-sector would experience a reduction by only 0.05% in SIM1 and 0.08% in SIM2. This result is not strange as livestock production relies more on crop outputs than fishery and forestry.

Among the non-agriculture sectors, the decline in the service sector is higher than the decline in the industrial sector. The damage is 0.40% in SIM1 and 0.65% in SIM2 for the service sector, while it is 0.18% in SIM1 and 0.39% in SIM2 for the industrial sector. This reveals that services do have strong linkage with the agricultural sector than the industrial sector does. The manufacturing sub-sector can still grow at very low crop productivity damages, i.e. in SIM1. This happens mainly due to the fact that some of the manufacturing activities (especially activities in the manufacturing non-processing sub-sector) have very low linkages with agricultural production. As expected, the growth in food processing sub-sector would shrink owning to its huge dependence on agricultural output for its intermediate inputs. However, the manufacturing non-processing sub-sector would expand by 0.25% and 0.35% in SIM1 and SIM2, respectively. The service sub-sectors, i.e. both private and public, would contract due to the crop productivity shocks.

There are possible reasons for the positive growth in non-processing manufacturing output despite the anticipated changes in climate conditions, while a large negative growth in the private services amounting 0.51% in SIM1 and 0.82% in SIM2. The latter happens mainly because trade services, hotels and catering, and business services which account a significant share of private services, are strongly linked to agricultural

outputs. The positive growth for the non-processing manufacturing sub-sector, however, is triggered by the increased demand for the sector's output while stakeholders take more increased and intensive adaptation and mitigation measures in order to reduce the harmful effects of climate change.

Table 5.1: Sectoral growth results

	Share of GDP (%)	Change from base (%)	
Sector	**Base**	**SIM1**	**SIM2**
GDP*	100.00	-3.83	-6.07
Agriculture	48.09	-7.59	-11.99
Cereal crops	13.82	-12.90	-20.26
Pulses and oil seeds	4.13	-13.36	-20.83
Enset	1.11	-11.40	-17.95
Horticulture	1.51	-9.71	-15.40
Export crops	8.39	-9.26	-14.86
Livestock	14.40	-1.83	-2.95
Other Agriculture	4.74	-0.05	-0.08
Non-agriculture	51.91	-0.35	-0.59
Industry	11.48	-0.18	-0.39
Mining	0.55	-0.21	-0.42
Manufacturing	4.81	0.03	-0.05
Food processing	2.38	-0.19	-0.47
Non-processing manufacturing	2.43	0.25	0.35
Other industry	6.12	-0.34	-0.65
Services	40.43	-0.40	-0.65
Private services	31.18	-0.51	-0.82
Public services	9.25	-0.03	-0.06

*GDP= real GDP at factor cost.

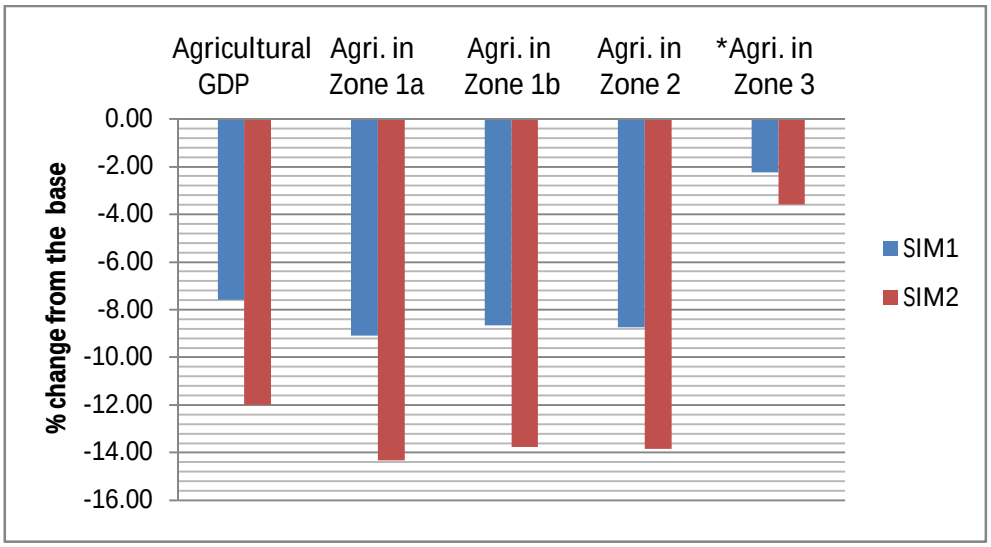
Source: CGE model simulations

The result further indicates that the impact on total agricultural growth is not uniformly distributed across different AEZs (figure 5.2). This result is in line with the findings of

Deressa and Hassan (2009) using the Ricardian model for Ethiopia. As can be seen from the figure, the highest reduction in agricultural growth would be in AEZ 1a (humid highlands region) amounting 9.10% in SIM1 and 14.34% in SIM2. It shows that future climate change will affect most the humid highlands region, a region where the dominant economic activity is cereal production and with suitable climate for agriculture.

The loss is, however, comparable in humid lowland and drought-prone regions. It is about 8.66% in SIM1 and 13.78% in SIM2 for AEZ 1b (humid lowland region), while in AEZ 2(drought-prone region) it amounts 8.76% in SIM1 and 13.85% in SIM2. However, AEZ 3 (pastoralist) would see the lowest reduction in total agricultural growth amounting 2.24% in SIM1 and 3.60% in SIM2. One of the reasons can be the region's negligible dependence on crop agriculture. In addition, livestock, which is the major agricultural activity in the region, is not as much vulnerable as crops to changes in climate conditions. Thus, areas that do not depend much on crop agriculture are not seriously vulnerable to future climate change.

Figure 5.2: Agricultural growth results across agro-ecologies



*Agri = Agriculture

Source: CGE model simulations

Moreover, the crop productivity shocks also results in change in the composition of sectoral trade (figure 5.3). The results indicate that exports of agricultural commodities would shrink in both simulations. However, the decline is higher in the second simulation following the pattern of production. This significant decline in the exports of agricultural commodities mainly resulted due to higher declines in the sectors' production, especially due to the higher decline in the production of cash crops. Hence, production will mainly be targeted to meet domestic demand for food and surplus production will become minimal which reduces exports.

Agricultural exports, being the major exports in Ethiopia accounting for about 43% of the total value of baseline exports, triggered the overall value of exports to contract as a result of the productivity damages. However, exports from the non-agriculture sectors increases by 6.07% in SIM1 and 9.69% in SIM2 owning to the increased exports both in

the industrial and service sectors. This result is contradictory with the finding of Zhai *et al*. (2009) for the People's Republic of China (PRC) though it is in the long-run.[11] The boom in industrial output exports is attributed mainly to the increase in manufacturing sub-sector exports. This happens due to higher productions in the non-processing manufacturing outputs. Whereas the expansion in service exports is mainly caused by the increase in private services exports which includes trade services (both wholesale and retail services), hotels and catering, and real estate services.

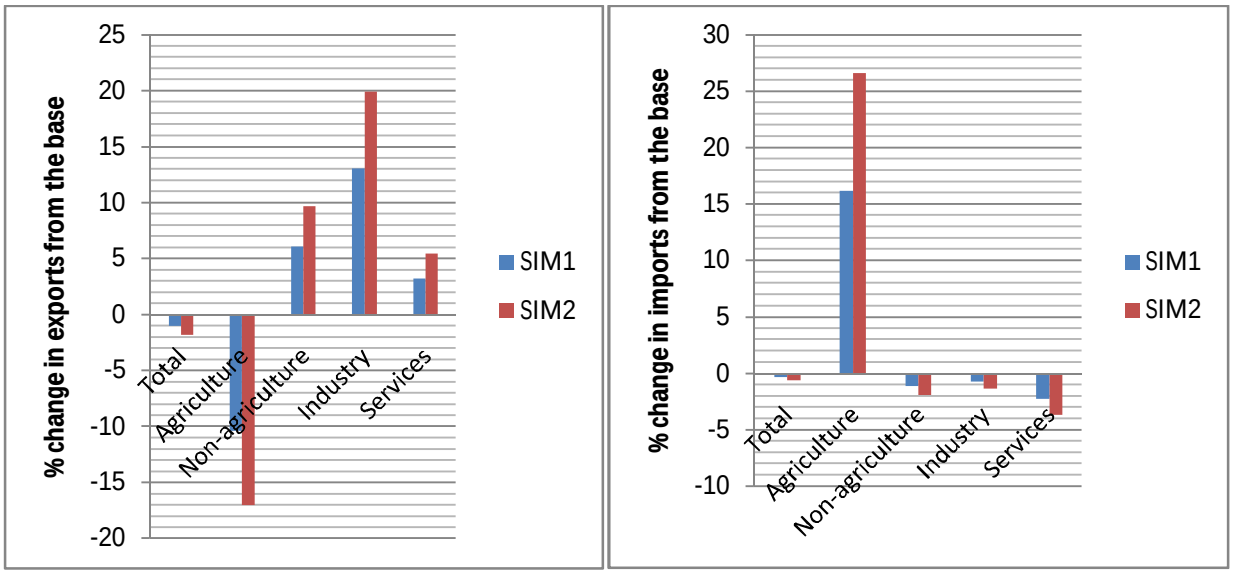
As for exports, the pattern of import growth is also affected by the climate change induced crop productivity damages. In the baseline case, almost 95% of the total imports are industrial and service outputs. Hence, as expected, the change in the overall value of imports follows the change in the non-agriculture imports. Non-agricultural import declines by 1.16% in SIM1 and 1.96% in SIM2 and in turn the overall value of imports shrinks by 0.36% and 0.64% in SIM1 and SIM2, respectively. However, the import of agricultural products expands by 16.23% and 26.58% in SIM1 and SIM2, respectively, higher increases being imports of wheat, pulses, leaf tea, tobacco and fish, among other things. This happens owning to two main reasons. First, domestic crop and hence total agricultural production declines significantly. This triggers higher imports of agricultural outputs to meet unsatisfied domestic demand. Second, the government also has limited resources to finance imports. Hence, there is ample reason,

[11] The result of Zhai *et al. (*2009) showed that PRC's exports will increase in the agricultural sector while it will decrease in the industrial and service sectors.

in a country of food insecurity, that it might prioritize spending its limited resources on the imports of agricultural outputs.

The import of industrial outputs accounts for about 71.2% of the total value of imports in the baseline scenario. However, the total value of imports of these outputs declines by 0.77% in SIM1 and 1.37% in SIM2 due to the crop productivity damages. The large decline in this sector would be in the imports of manufacturing outputs and to a smaller extent in the mining imports. This resulted mainly because of the increase in domestic production of the non-processing manufacturing activities. Similarly, the total import of services is also contracted by 2.31% in SIM1 and 3.69% in SIM2. This contraction is mainly attributed to the decline in the imports of private services like hotels and catering, trade services, transport, communications and financial services.

Figure 5.3: Comparing the impacts on the real value of exports and imports



Source: CGE model simulations

5.2.3 Impacts on Households

Table 5.2 presents the impacts on household incomes. Notice that household incomes are calculated in real terms being adjusted for by the price changes. As can be seen from the table, both rural and urban households would experience a fall in their real incomes compared to the base case. Total household income would fall by 10.06% and 15.60% in SIM1 and SIM2, respectively. However, the brunt of these losses is borne by the urban households. This happens due to the fact that majority of the urban households reside in smaller centers whose incomes entirely depend on agricultural outputs unlike the rural households who have a more diversified source of income. In addition, with changes in climate conditions, there is every reason that farmers switch from cultivating lower value crops to higher value ones. Hence, they can buffer the damages on their real incomes even though actual production declines. There is no such option for the urban households and thus would experience higher losses in incomes.

It terms of household groups, none of them will have increased incomes. For the rural households, except for households in AEZ 3 (pastoralist) in which the result is reverse, it revealed that the decline in incomes envisage relatively larger losses for the poor households compared to the well-off rural household groups. This pattern is the same in the case of urban households residing in small urban centers. However in case of large urban centers, the well-off groups experience larger losses in incomes compared to the poor households. The pattern of decline in income across households is identical for both simulations.

Table 5.2: The impact on household income

		Initial value*	% change in income from the base	
	Households	Base	SIM1	SIM2
	All households	134.29	-10.06	-15.60
	Rural Households	100.44	-9.79	-15.23
	Urban Households	33.84	-10.85	-16.71
Zone 1a	Rural Poor *	13.66	-9.99	-15.56
	Rural Non-poor	29.62	-9.97	-15.55
Zone 1b	Rural Poor	5.86	-10.03	-15.61
	Rural Non-poor	12.16	-9.33	-14.42
Zone 2	Rural Poor	10.79	-9.82	-15.28
	Rural Non-poor	22.59	-9.54	-14.85
Zone 3	Rural Poor	2.09	-9.52	-14.83
	Rural Non-poor	3.68	-10.31	-16
Small Centers	Urban Poor	3.95	-11.61	-17.88
	Urban Non-poor	14.56	-11.6	-17.86
Big Centers	Urban Poor	2.66	-9.92	-15.3
	Urban Non-poor	12.67	-9.94	-15.32

*The initial value is expressed in billion Ethiopian birr.
*Poor imply all households falling into the lowest two per capita expenditure quintiles (i.e., the poorest 40% of the population).

Source: CGE model simulations

In order to give a bird's eye view concerning the impacts on household welfare, the equivalent variation (EV) is calculated. Under the EV approach, the idea is to measure in money terms, how much income needs to be given to the consumer at the "pre-(non) policy change" level of prices in order to enable him/her to enjoy the utility level which arises after the (non)policy change is effected ("post-(non)policy change level of utility"). Figure 5.4 presents the simulated impacts on household welfare. Positive EV

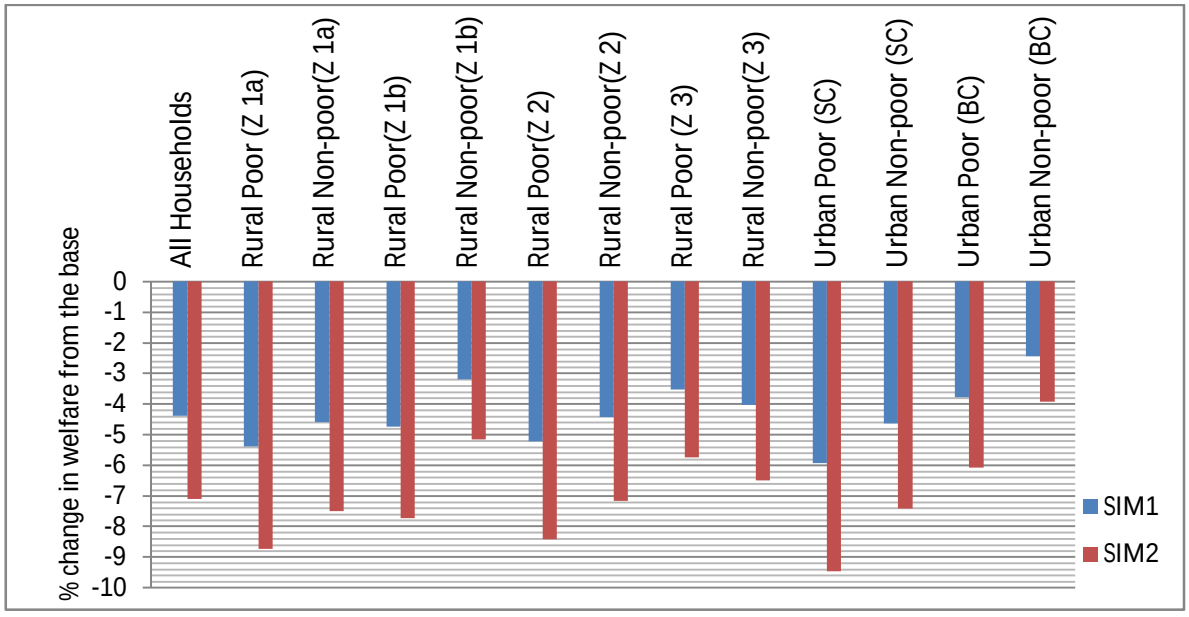
values are the manifestation of positive real consumption growth while negative EV values are associated with negative real consumption.

As for the changes in household income, the welfare of households also tends to be affected. The productivity shocks in both simulations estimated a negative growth in total household welfare compared to the base case by about 4.38% and 7.09% in SIM1 and SIM2, respectively. For the rural household groups, welfare losses follow the pattern of decline in their real incomes, i.e., welfare losses are higher for the poor households compared to the losses of non-poor households and the opposite is true in AEZ 3. The difference in impacts across households happens owning to the differences in capacity to adapt and cope with the impact of climate change. Non-poor households are endowed with plenty of resources to undertake varieties of adaptation and coping mechanisms which the poor households lack. As a result, welfare losses due to crop productivity damages are smaller for the well-off groups. However, the difference is negligible between households in the drought prone AEZ and the result is totally reverse in the pastoralist AEZ. In the pastoralist AEZ, welfare losses amount 3.53% and 5.74% for the poor groups, while it amounts 4.03% and 6.5% for non-poor households in SIM1 and SIM2, respectively.

These agro-ecologies, i.e., drought-prone and pastoralist AEZs, are the already affected areas as a result of past changes in climate conditions. Consequently, there are strong interventions by the government and private stakeholders, like the productivity safety net program, in order to improve the capacity of poor households to adapt and cope

with the impacts of climate change. These interventions are further expected to increase with future changes in climate and may result in lower losses in welfare of poor households as compared to the losses incurred by non-poor households in the pastoralist AEZ and a comparable decline in welfare of both households in the drought prone AEZ. Similarly, from the urban households, it is the poor that would see higher welfare losses than the non-poor households in both centers. Overall, the welfare declines would be highest for the urban poor households that reside in smaller centers. This is attributed to the fact that these centers do not have any significant economic activity. Their means of livelihood is from trade services which entirely depend on agricultural outputs unlike the rural households and the urban households that live in big centers who have a more diversified source of livelihood.

Figure 5.4: The impact on household welfare



*Z=agro-ecological zone, SC=smaller centers and BC=big centers

Source: CGE model simulations

5.3 Sensitivity Analysis

The CGE model is carried out based on certain assumptions concerning its parameters. These include the elasticity of substitution between primary factors in production, domestic and imported goods in the domestic demand, and domestic and external markets for the suppliers. Hence to check the robustness of the results discussed above, the results after making a significant change(a 50% reduction from the original values) on the said elasticity parameters is compared with the original ones. The results are, therefore, found to be similar in terms of sign. As a result, it can be concluded that the CGE results discussed thus far are robust despite the baseline assumptions.

CHAPTER SIX

CONCLUSIONS AND IMPLICATIONS

6.1 Conclusions

This paper has examined the potential impacts of climate change on the Ethiopian economy. In doing so, it employs a static computable general equilibrium (CGE) model developed by Lofgren *et al*. (2002). The results suggest that the macroeconomic impacts of crop damages caused by climate change are overwhelming. Total agricultural production declines significantly due to the anticipated declines in crop agriculture. However, these impacts are not uniformly distributed across agro-ecologies of the country. For instance, humid highlands region bear the brunt of agricultural losses, while the impact on pastoralist region is smallest due to its little dependence on crop production. This implies that regions with strong dependence on crop agriculture would be affected much due to the anticipated changes in climate conditions.

In terms of sectoral distribution, the impacts are much higher in the service sector next to agricultural production. This is attributed to the fact that services have strong linkages with agriculture than the industry does. But, the impact on industrial sector is found to be moderate compared with both agriculture and services. Notice that non-processing manufacturing sub-sector have positively responded to crop productivity damages. Hence, future climate change would be a strong constraint for those sectors that have firm linkages with agriculture. Moreover, some significant adjustments in sectoral exports and imports have been observed due to the changes in climate.

Climate change does not only result in macroeconomic and sectoral repercussions but also affects income and welfare of households. The results indicated that all households would see lower incomes compared to the base case. In particular, the decline in income has been higher for the poor households both in rural and urban areas. Furthermore, all household groups will experience reduced welfare compared to the base case due to crop productivity damages and the resultant impacts on production and incomes, among other things.

6.2 Implications

The effect of climate change on crop production and all the rest of the economy is apparent in Ethiopia. Its negative impact has been already felt in the country. These impacts are going to be exacerbated with future changes in climate. Hence, there is a need to counteract these impacts, especially on agricultural production by taking improved adaptation actions at the farm level. The government of Ethiopia, therefore, should consider scaling up the existing ones and designing and implementing new adaptation mechanisms to reduce the harmful effects of climate change. These interventions are further suggested not to be uniform throughout the country. Thus, future studies shall consider identifying specific adaptation interventions for each of AEZs of the country. This study further recommends much wider research in the area, especially concerning the long-run impacts, as the knowledge about the economy-wide impact of climate change in Ethiopia is limited.

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Appendices

Appendix 1: CGE Model Sets, Parameters, and Variables

Symbol	Explanation	Symbol	Explanation
Sets			
$\alpha \in A$ –	activities	$c \in CX\ (\subset C)$	commodities with domestic production
$\alpha \in ALEO (\subset A)$	activities with a Leontief function at the top of the technology nest	$f \in F$	factors
		$i \in INS$	institutions (domestic and rest of the world)
$c \in C$	commodities		
$c \in CD (\subset C)$	commodities with domestic sales of domestic output	$i \in INSD (\subset INS)$	domestic institutions
		$\in INSDNG (\subset INSD)$	domestic nongovernmental institutions
$c \in CDN (\subset C)$	commodities not in CD		
$c \in CM (\subset C)$	imported commodities	$h \in H (\subset INSDNG)$	households
$c \in CMN (\subset C)$	commodities not in CM		
$c \in CT (\subset C)$	transactions service commodities		
Parameters			
Latin symbols			
$cwts_c$	weight of commodity c in the $\overline{CPI}$	$qdst_c$	quantity of stock change
$dwts_c$	weight of commodity c in the producer price index	$\overline{qg_c}$	base-year quantity of government demand
ica_{ca}	quantity of c as intermediate input per unit of activity a	$\overline{qinv_c}$	base-year quantity of private investment demand
$icd_{cc'}$	quantity of commodity c as trade input per unit of c' produced and sold domestically	$shif_{if}$	share for domestic institution i in income of factor f

$ice_{cc'}$ quantity of commodity c as trade input per exported unit of c'	$shii_{ii'}$ share of net income of i' to i ($i' \in INSDNG'$; $i \in INSDNG$)
$icm_{cc'}$ quantity of commodity c as trade input per imported unit of c'	$t\alpha_a$ tax rate for activity a
$inla_a$ quantity of aggregate intermediate input per activity unit	te_c export tax rate
iva_a quantity of value-added per activity unit	tf_f direct tax rate for factor f
$\overline{mps_i}$ base savings rate for domestic institution i	$\overline{tins_i}$ exogenous direct tax rate for domestic institution i
$mps01_i$ 0-1 parameter with 1 for institutions with potentially flexed direct tax rates	$tins01_i$ 0 1 parameter with 1 for institutions with potentially flexed direct tax rates
pwe_c – export price (foreign currency)	tm_c import tariff rate
pwm_c – import price (foreign currency)	tq_c rate of sales tax
	$trnsfr_{if}$ transfer from factor f to institution i
	tva_a rate of value-added tax for activity a
Greek symbols	
α_a^{va} efficiency parameter in the CES value-added function	δ_c^t CET function share parameter
α_a^{ac} shift parameter for domestic commodity aggregation function	δ_{fa}^{va} CES value-added function share parameter for factor f in activity a
α_c^q Armington function shift parameter	γ_{ch}^m subsistence consumption of marketed commodity c for household h
α_c^t CET function shift parameter	γ_{ach}^h subsistence consumption of home commodity c from activity a for household h
β_{ach}^h marginal share of consumption spending on home commodity c	

from activity a for household h β_{ch}^{m} marginal share of consumption spending on marketed commodity c for household h δ_{ac}^{ac} share parameter for domestic commodity aggregation function δ_{c}^{q} Armington function share parameter	θ_{ac} yield of output c per unit of activity a ρ_{a}^{va} CES value-added function exponent ρ_{c}^{ac} domestic commodity aggregation function exponent ρ_{c}^{q} Armington function exponent ρ_{c}^{t} CET function exponent
Exogenous Variables	
$\overline{CPI}$ consumer price index $\overline{DTINS}$ change in domestic institution tax share (=0 for base; exogenous variable) $\overline{FSAV}$ foreign saving(FCU) $\overline{GADJ}$ government consumption adjustment factor $\overline{IADJ}$ investment adjustment factor	$\overline{MPSADJ}$ savings rate scaling factor (=0 for base) $\overline{QFS}_{f}$ quantity supplied of factor $\overline{TINSADJ}$ direct tax scaling factor (=0 for base; exogenous variable) $\overline{WFDIST}_{fa}$ wage distortion factor for factor f in activity a
Endogenous variables	
$DMPS$ change in domestic institution savings rates (=0 for base; exogenous variable) DPI producer price index for domestically marketed output EG government expenditure EH_{h} consumption spending	QG_{c} government consumption demand for commodity c QH_{ch} quantity consumed of commodity c by household h QHA_{ach} quantity of household home consumption of commodity c from activity a for household h

for household

EXR exchange rate (LCU per unit of FCU)

$GOVSHR$ government consumption share in nominal absorption

$GSAV$ government savings

$INVSHR$ investment share in nominal absorption

MPS_i marginal propensity to save for domestic non-government institution (Exogenous variable)

PA_a activity price (unit gross revenue)

PDD_c demand price for commodity produced and sold domestically

PDS_c supply price for commodity produced and sold domestically

PE_c export price (domestic currency)

$PINTA_a$ aggregate intermediate input price for activity a

PM_c import price (domestic currency)

PQ_c composite commodity price

PVA_a value-added price (factor income per unit of activity)

PX_c aggregate producer price for commodity

$PXAC_{ac}$ producer price of commodity c for activity a

$QINTA_a$ quantity of aggregate intermediate input

$QINT_{ca}$ quantity of commodity c as intermediate input to activity a

$QINV_c$ quantity of investment demand for commodity c

QM_c quantity of imports of commodity c

QQ_c quantity of goods supplied to domestic market (composite supply)

QT_c quantity of commodity demanded as trade input

QVA_a quantity of (aggregate) value-added

QX_c aggregated marketed quantity of domestic output of commodity c

$QXAC_{ac}$ quantity of marketed output of commodity c from activity a

$TABS$ total nominal absorption

$TINS_i$ direct tax rate for institution i ($i \in INSDNG$)

$TRII_{ii'}$ transfers from institution i' to i (both in the set INSDNG)

WF_f average price of factor f

YF_f income of factor f

QA_a quantity (level) of activity	YG government revenue
QD_c quantity sold domestically of domestic output	YI_i income of domestic nongovernment institution
QE_c quantity of exports	YIF_{if} income to domestic institution i from factor f
QF_{fa} quantity demanded of factor f from activity a	

Appendix 2: CGE Model Equations

- **Price Block**

Import price

$$PM_c = pwm_c \cdot (1 + tm_c) \cdot EXR + \sum_{c' \in CT} PQ_{c'} \cdot icm_{c'c} \qquad c \in CM \qquad \text{..... (1)}$$

Export price[12]

$$PE_c = pwe_c \cdot (1 - te_c) \cdot EXR - \sum_{c' \in CT} PQ_{c'} \cdot ice_{c'c} \qquad c \in CE \qquad \text{..... (2)}$$

Demand price of domestic non-traded goods

$$PDD_c = PDS_c + \sum_{c' \in CT} PQ_{c'} \cdot icd_{c'c} \qquad c \in CD \qquad \text{..... (3)}$$

Absorption

$$PQ_c \cdot (1 - tq_c) \cdot QQ_c = PDD_c \cdot QD_c + PM_c \cdot QM_c \qquad c \in (CD \cup CM) \qquad \text{..... (4)}$$

Marketed output value

$$PX_c \cdot QX_c = PDS_c \cdot QD_c + PE_c \cdot QE_c \qquad c \in CX \qquad \text{..... (5)}$$

Activity price

$$PA_a = \sum_{c \in C} PXAC_{ac} \cdot \theta_{ac} \qquad a \in A \qquad \text{..... (6)}$$

Aggregate intermediate input price

$$PINTA_a = \sum_{c \in C} PQ_c \cdot ica_{ca} \qquad a \in A \qquad \text{..... (7)}$$

Activity revenue and costs

$$PA_a \cdot (1 - ta_a) \cdot QA_a = PVA_a \cdot QVA_a + PINTA_a \cdot QINTA_a \qquad a \in A \qquad \text{..... (8)}$$

[12] Notice that there is no export tax in Ethiopia.

Consumer price index

$$\overline{CPI} = \sum_{c \in C} PQ_c \cdot cwts_c \qquad \text{..... (9)}$$

Producer price index for non-traded market output

$$DPI = \sum_{c \in C} PDS_c \cdot dwts_c \qquad \text{..... (10)}$$

- **Production and Trade Block**

Leontief Technology: Demand for aggregate value-added

$$QVA_a = iva_a \cdot QA_a \qquad a \in ALEO \qquad \text{..... (11)}$$

Leontief Technology: Demand for aggregate intermediate input

$$QINTA_a = inta_a \cdot QA_a \qquad a \in ALEO \qquad \text{..... (12)}$$

Value-added and factor demands

$$QVA_a = \alpha_a^{va} \cdot \left(\sum_{f \in F} \delta_{fa}^{va} \cdot QF_{fa}^{-\rho_a^{va}} \right)^{-\frac{1}{\rho_a^{va}}} \qquad a \in A \qquad \text{.....} \quad (13)$$

Factor demand[13]

$$WF_f \cdot \overline{WFDIST}_{fa} = PVA_a (1 - tva_a) \cdot QVA_a \cdot \left(\sum_{f \in F'} \delta_{fa}^{va} \cdot QF_{fa}^{-\rho_a^{va}} \right)^{-1} \cdot \delta_{fa}^{va} \cdot QF_{fa}^{-\rho_a^{va}-1} \quad a \in A;\ f \in F$$

..... (14)

Disaggregated intermediate input demand

$$QINT_{ca} = ica_{ca} \cdot QINTA_a \qquad a \in A;\ c \in C \qquad \text{..... (15)}$$

Commodity production and allocation

$$QXAC_{ac} + \sum_{h \in H} QHA_{ach} = \theta_{ac} \cdot QA_a \qquad a \in A;\ a \in CX \qquad \text{..... (16)}$$

Output aggregation function

[13] Notice that there is no value added tax on activities in Ethiopia.

$$QX_c = \alpha_c^{ac} \cdot \left(\sum_{a \in A} \delta_{ac}^{ac} \cdot QXAC_{ac}^{-\rho_c^{ac}} \right)^{-\frac{1}{\rho_c^{ac}-1}} \qquad c \in CX \quad \text{..... (17)}$$

First-order condition for output aggregation function

$$PXAC_{ac} = PX_c \cdot QX_c \left(\sum_{a \in A'} \delta_{ac}^{ac} \cdot QXAC_{ac}^{-\rho_c^{ac}} \right)^{-1} \cdot \delta_{ac}^{ac} \cdot QXAC_{ac}^{-\rho_c^{ac}-1} \qquad a \in A;\ c \in CX \quad \text{..... (18)}$$

Output transformation (CET) function

$$QX_c = \alpha_c^t \cdot \left(\delta_c^t \cdot QE_c^{\rho_c^t} + (1-\delta_c^t) \cdot QD_c^{\rho_c^t} \right)^{\frac{1}{\rho_c^t}} \qquad c \in (CE \cap CD) \quad \text{..... (19)}$$

Export – Domestic supply ratio

$$\frac{QE_c}{QD_c} = \left(\frac{PE_c}{PDS_c} \cdot \frac{1-\delta_c^t}{\delta_c^t} \right)^{\frac{1}{\rho_c^t-1}} \qquad c \in (CE \cap CD) \quad \text{..... (20)}$$

Output transformation for domestically sold outputs without exports and for exports without domestic sales

$$QX_c = QD_c + QE_c \qquad c \in (CD \cap CEN) \cup (CE \cap CDN) \quad \text{..... (21)}$$

Composite supply (Armington) function

$$QQ_c = \alpha_c^q \cdot \left(\delta_c^q \cdot QM_c^{-\rho_c^q} + (1-\delta_c^q) \cdot QD_c^{-\rho_c^q} \right)^{-\frac{1}{\rho_c^q}} \qquad c \in (CM \cap CD) \quad \text{..... (22)}$$

Import- domestic demand ratio

$$\frac{QM_c}{QD_c} = \left(\frac{PDD_c}{PM_c} \cdot \frac{\delta_c^q}{1-\delta_c^q} \right)^{\frac{1}{1+\rho_c^q}} \qquad c \in (CM \cap CD) \quad \text{..... (23)}$$

Composite supply for non-imported output and non-produced imports

$$QQ_c = QD_c + QM_c \qquad c \in (CD \cap CMN) \cup (CM \cap CDN) \quad \text{..... (24)}$$

Demand for transactions services

$$QT_c = \sum_{c' \in C'} (icm_{cc'} \cdot QM_{c'} + ice_{cc'} \cdot QE_{c'} + icd_{cc'} \cdot QD_{c'}) \qquad c \in CT \quad \text{..... (25)}$$

- **Institutions Block**

Factor income

$$YF_f = \sum_{a \in A} WF_f \cdot \overline{WFDIST}_{fa} \cdot QF_{fa} \qquad f \in F \quad \text{..... (26)}$$

Institutional factor incomes

$$YIF_{if} = shif_{if} \cdot \left[(1 - tf_f) \cdot YF_f - trnsfr_{rowf} \cdot EXR \right] \qquad i \in INSD;\ f \in F \quad \text{..... (27)}$$

Income of domestic, non-government institutions

$$YI_i = \sum_{f \in F} YIF_{if} + \sum_{i' \in INSDNG'} TRII_{ii'} + trnsfr_{igov} \cdot \overline{DPI} + trnsfr_{irow} \cdot EXR \qquad i \in INSDNG \quad \text{..... (28)}$$

Intra-institutional transfers

$$TRII_{ii'} = shii_{ii'} \cdot (1 - MPS_{i'}) \cdot (1 - TINS_{i'}) \cdot YI_{i'} \qquad i \in INSDNG;\ i' \in INSDNG' \quad \text{..... (29)}$$

Household consumption expenditure

$$EH_h = \left(1 - \sum_{i \in INSDNG} shii_{ih} \right) \cdot (1 - MPS_h) \cdot (1 - TINS_h) \cdot YI_h \qquad h \in H \quad \text{..... (30)}$$

Household consumption spending on marketed commodities

$$PQ_c \cdot QH_{ch} = PQ_c \cdot \gamma^m_{ch} + \beta^m_{ch} \cdot \left(EH_h - \sum_{c' \in C} PQ_{c'} \cdot \gamma^m_{c'h} - \sum_{a \in A} \sum_{c' \in C} PXAC_{ac'} \cdot \gamma^h_{ac'h} \right) \qquad c \in C;\ h \in H$$

..... (31)

Household consumption spending on home commodities

$$PXAC_{ac} \cdot QHA_{ach} = PXAC_{ac} \cdot \gamma^h_{ach} + \beta^h_{ach} \cdot \left(EH_h - \sum_{c' \in C} PQ_{c'} \cdot \gamma^m_{c'h} - \sum_{a \in A} \sum_{c' \in C} PXAC_{ac'} \cdot \gamma^h_{ac'h} \right)$$

$$a \in A;\ c \in C;\ h \in H \qquad \text{.....(32)}$$

Investment demand

$$QINV_c = \overline{IADJ} \cdot \overline{qinv}_c \qquad c \in CINV \quad \text{..... (33)}$$

Government consumption demand

$$QG_c = \overline{GADJ} \cdot \overline{qg}_c \qquad c \in C \quad \text{..... (34)}$$

Government revenue[14]

$$YG = \sum_{i \in INSDNG} TINS_i \cdot YI_i + \sum_{f \in F} tf_f \cdot YF_f + \sum_{a \in A} tva_a \cdot PVA_a \cdot QVA_a$$

$$+ \sum_{a \in A} ta_a \cdot PA_a \cdot QA_a + \sum_{c \in CM} tm_c \cdot pwm_c \cdot QM_c \cdot EXR + \sum_{c \in CE} te_c \cdot pwe_c \cdot QE_c \cdot EXR$$

$$+ \sum_{c \in C} tq_c \cdot PQ_c \cdot QQ_c + \sum_{f \in F} YIF_{govf} + trnsfr_{govrow} \cdot EXR \quad \text{..... (35)}$$

Government expenditure

$$EG = \sum_{c \in C} PQ_c \cdot QG_c + \sum_{i \in INSDNG} trnsfr_{igov} \cdot \overline{DPI} \quad \text{..... (36)}$$

- **System Constraint Block**

Factor markets

$$\sum_{a \in A} QF_{fa} = \overline{QFS}_f \qquad f \in F \quad \text{..... (37)}$$

Composite commodity markets

$$QQ_c = \sum_{a \in A} QINT_{ca} + \sum_{h \in H} QH_{ch} + QG_c + QINV_c + qdst_c + QT_c \qquad c \in C \quad \text{..... (38)}$$

Current account balance for the ROW (in foreign currency)

$$\sum_{c \in CM} pwm_c \cdot QM_c + \sum_{f \in F} trnsfr_{rowf} = \sum_{c \in CE} pwe_c \cdot QE_c + \sum_{i \in INSD} trnsfr_{irow} + \overline{FSAV} \quad \text{..... (39)}$$

[14] From the right hand expressions, the second, third, fourth and sixth terms does not apply in the Ethiopian case as there are no direct taxes on factors, value-added taxes, activity and export taxes in the country.

Government balance

$$YG = EG + GSAV \qquad \text{…….. (40)}$$

Direct institutional tax rates

$$TINS_i = \overline{tins}_i \cdot (1 + \overline{TINSADJ} \cdot tins01_i) + \overline{DTINS} \cdot tins01_i \qquad i \in INSDNG \text{ …..... (41)}$$

Institutional savings rates

$$MPS_i = \overline{mps}_i \cdot (1 + \overline{MPSADJ} \cdot mps01_i) + DMPS \cdot mps01_i \qquad i \in INSDNG \text{ …..... (42)}$$

Savings-investment balance

$$\sum_{i \in INSDNG} MPS_i \cdot (1 - TINS_i) \cdot YI_i + GSAV + EXR \cdot \overline{FSAV} = \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c \text{ …... (43)}$$

Total absorption

$$TABS = \sum_{h \in H} \sum_{c \in C} PQ_c \cdot QH_{ch} + \sum_{a \in A} \sum_{c \in C} \sum_{h \in H} PXAC_{ac} \cdot QHA_{ach} + \sum_{c \in C} PQ_c \cdot QG_c$$

$$+ \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c \qquad \text{…..... (44)}$$

Ratio of investment to absorption

$$INVSHR \cdot TABS = \sum_{c \in C} PQ_c \cdot QINV_c + \sum_{c \in C} PQ_c \cdot qdst_c \qquad \text{…..... (45)}$$

Ratio of government consumption to absorption

$$GOVSHR \cdot TABS = \sum_{c \in C} PQ_c \cdot QG_c \qquad \text{…..... (46)}$$

I, the undersigned, declare that this thesis is my original work and has not been presented for a degree in any other university, and that all source of materials used for the thesis have been duly acknowledged.

Declared by:

Name: _____

Signature: _____

Date: _____

Confirmed by:

Name: _____

Signature: _____

Date: _____

Place and Date of Submission: _____