

**THE EFFECT OF CLIMATE CHANGE INDUCED PRODUCTIVITY CHANGE  
ON FOOD SECURITY AND FOOD MARKET OF ETHIOPIA: CGE MODELING**

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School of Graduate Studies

This is to certify that the thesis prepared by Wondmunegn Kebede, entitled: *The Effect of Climate Change Induced Productivity Change on Food Security and Food Market of Ethiopia: CGE Modeling* and submitted in the partial fulfillment of the requirement for the degree of Master of Science in Economics (Policy Economic Analysis) complies with the regulations of the university and meets the accepted standards with respect to the originality and quality.

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## ABSTRACT

The Effect of Climate Change Induced Productivity Change on Food security and Food market of Ethiopia: CGE Modeling.

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Addis Ababa University, June 2012

Ethiopia is known as food insufficient country. It depends mainly on its agricultural sector for food production which is rainfall dependent. The performance of this sector has remained low mainly because of recurrent drought inherently happened as a result of climate change. Owing to the variability of the rainfall and temperature in the country, Climate change is anticipated to have an impact on the productivity of the agricultural sector. The thesis is therefore simulates the effect of climate change induced agricultural productivity change on food security and food market of Ethiopia. A recursive dynamic CGE model is used with three climate scenarios (CGCM2, PCM and HadCM3). In the finding, it is revealed that food availability problem is stressed from a decline in per capita food production with negative yield growth elasticity and an increase in food supply price under climate change. In addition, food access problem is also hassled with a reduction in per capita income and per capita food consumption expenditure. In a nutshell, food poverty is intensified from general welfare loss under climate change. The HadCM3 climate projection provides the worst scenario followed by the CGCM2 climate forecasting. It has generalized that climate change will be the main challenge to the future on the food security problem of Ethiopia. Finally, the paper recommended that climate change adaptation is required to create resilience capacity; diversification of the income source for both the rural and urban households and improving the farming technology and practice is suggested. It is also required to expand farm irrigation, develop road infrastructure, establishing efficient climate forecasting and communication technology, and improving market efficiency.

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## List of Acronyms



AEZ	Agro-Ecological Zones
CC	Climatic Change
CES	Constant Elasticity of Substitution
CGCM	Coupled Global Climate Model
CGE	Computational General Equilibrium
CSA	Central Statistical agency
EDRI	Ethiopian Development Research Institute
EEPFE	Environmental Economics Policy Forum for Ethiopia
FAO	Food and Agricultural Organization
GCM	General Circulation Model
GDP	Gross Domestic Product
GIM	Global Impact analysis Model
GTAP	Global Trade Analysis and Policy Model
HaDCM	Hadley Center Coupled Climate Model
IFPRI	International Food Policy Research Institute
IPCC	Intergovernmental Panel on Climate Change
MoFED	Ministry of Finance and Economic Development
MPS	Marginal Propensity to save
NAPA	National Adoption Program of Action
NMSA	National Metrological Service Agency
PASDEP	A Plan for Accelerated & sustained Development to End Poverty



	Alleviation
PCM	Parallel Climate Model
POP	Population
SAM	Social Accounting Matrix
SRES	Special Report on emission scenario
TFP	Total factor Productivity
WFS	World Food Summit

## CHAPTER ONE

### Introduction

#### 1.1. General Back Ground of the Study

Ethiopia is known to be economically underdeveloped country and its economy depends mainly on the agricultural sector. This sector is identified for its immense contribution to the economy of the country: it accounts about 42% of the country's gross domestic product (MoFED, 2009/10), produces 80 percent of its exports, and nearly about 84 percent of the country's population depends on this sector for their livelihood (CSA, 2011).

However, the sector has stayed less productive for long period of time and the country failed to achieve food security, even it is far behind achieving food sufficiency. Many reasons can be mentioned for poor performance of the agricultural sector such as poor agricultural technology and traditional farming practice, fragmented farming because of population growth, loosing soil fertility and degradation with over exploitation and environmental change, ineffective policy, less developed infrastructure and market institutions. But most immanently it has accounted that drought because of climate variation is a major cause for poor performance of the sector which makes the country to depend on food aid (Temesgen, 2007).

The country has exhibited a remarkable climate changes in the past characterized with extreme drought, floods, increasing and decreasing temperature and precipitation. To this fact, the National Metrological Service Agency of Ethiopia (NMSA) in its national adoption program of action (NAPA), has portrayed that average annual rainfall of the country showed a high level of variability over the past years though the trend remained more or less constant (NMS , 2007). The metrological service agency in its 2001 document has also indicated that the annual minimum temperature over the country has been increasing by about 0.25°C every 10 years, while annual maximum temperature has been increasing by about 0.1°C in every decade (NMSA, 2001). In addition, it is empirically verified that the frequency and spatial coverage of drought is getting increasing in the country in all over the regions (Lautze, *et al.*, 2003).

In the instance of this climate variability and Ethiopia as part of tropical region, is anticipated to be affected by climate change. The effect will be high as the country is agrarian economy which vastly depends on rain fed agriculture. In addition, the country has limited capacity to resist the impact of climate change. The reason is because there are few infrastructures and poor production technology and practice especially in the rural sector. Thus, the agricultural sector and its implication for food security warrant a policy and action reorientation in line with climate change (Deressa, *et al.*, 2009). The impact of climate change on food security of the country is a critical area of investigation to inform sound policies for adaptation options. Based on this back ground this thesis is intended to make investigation about the impact of climate change on food security of the country.

## 1.2. Statement of the Problem and Research Questions of the Study

Ethiopia as a developing country is characterized with a high food poverty incidence. Regardless of substantial resources allocated each year to reduce the number of food insecure households, both chronic and transitory food insecurity problems are continuing in the country at the household level (Zappacosta, *et al.*, 2010). The food insecurity problem of the country is compounded by recurrent droughts and famine that cycle in and out (Zenebe, *et al.*, 2011).

The country as an agrarian economy is largely depends on its agricultural sector to meet its domestic food demand. Nonetheless, this sector is characterized with poor productivity which makes the country to be food insufficient.

The agricultural sector is characterized with poor production technology practice and highly depending on rainfall and natural inputs that are directly related to climatic conditions. Thus, any variability with regard to the climate condition like rainfall, temperature and soil fertility will predominantly matter the productivity of the sector.

Drought and famine are rooted with deep poverty in the country's history inherently caused by climate and some geological change. Thus, the problem of weather change can be regarded for the country as the problem of survival. Indeed, farmers' dependency on rainfall and its erratic patterns have largely contributed to the food shortages and crises (Zenebe, *et al.*, 2011). For this reason, agriculture and food security are identified to be the key sectors for intervention under climate change.

Several empirical works have been undertaken in order to investigate the impact of climate change on Ethiopian agriculture with different research methodologies. Partial equilibrium analysis of the Recardian methodology were applied by (Temesgen, and Hassan, 2009), ( Meseret, 2009), (Yun and Ringler, 2010), and (Zenebe, *et al.*, 2011). Moreover, general equilibrium analysis of CGE modeling were implemented by (Jesper, *et al.*, 2011), and (Zappacosta, *et al.*, 2010) with the general theme of the impact of climate change on agriculture.

All these papers tried to assess the food security impact of climate change only from the production side i.e. food availability and supply. However, the scope of food security problem is beyond food availability. In addition to food availability the food security also encompasses the problem of food access, stability, and utilization. Their focus only on the production side of food security problem is the critical gap of the previous studies that were conducted so as to investigate the impact of climate change on food security. As many of the African rural and urban poor depend on agriculture for their income source, it is predicted that climate change will also challenge food stability (Medany, *et al.*, 2006), (FAO, 2008), and (FAO, 2010). Therefore, food access should be taken into account in assessing food security problem.

Moreover, many of the studies that were specific to the effect of climate change on food security problem have done at household level by using micro econometric tools. They have failed to address the fact that climate change is also compromising the macro

economic variables like national income which has an implication for food importing capacity. The analysis of climate change impact on food availability at national level enables to evaluate allocation problem which depend on the level of market integration. High food production and enough purchasing power alone do not guarantee food security in the area where allocation problem is found as a result of market disintegration.

Therefore, this thesis is designed to bridge the gap by making a study on the effect of climate change induced productivity changes on food market and food security at national level. To this problem the following research questions are considered to be appraised.

- How climatic change induced productivity change is affecting food security?
- What are the likely effect of climate change on market price and food supply, on household income, on food consumption expenditure level and variability of the rural and urban households' consumption trend?

### **1.3. Objectives**

The general objective of the paper is to simulate the effect of climate change on food security status of the country using CGE model.

The specific objectives are:

- To assess the effect of climate change on food availability, households' food purchasing power, and food consumption expenditure trend.

- To simulate and compare the food security impacts on urban and rural household food consumption trend disaggregated with agro-ecological zones.
- To examine the climate change impact on general welfare of households disaggregated with agro-ecological zones.

#### **1.4. Significance of the study**

This study simulates the economic impact of climate change on food security of the country using CGE modeling. In the result it provides a quantified and scaled assessment about the impact of climate change on food security at national level; hence the finding will give a clear direction for policy designing in adapting climate change.

Climate change and its impact is an emerging global concern. The output of the thesis will serve as supplementary information to the available literature as there are only few studies devoted to deal with the impact of climate change on food security with specific indicators using a general equilibrium analysis at a country level especially for Ethiopia.

#### **1.5. Scope and Limitations of the Study**

In investigating the effect of climate change on food security in Ethiopia, it is presumed that the effect will be transmitted through market variables initially causing the productivity to change. Food availability is indicated using a change in per capita food production, imported food, and domestic food supply price. Food access is also indicated with a change in per capita income, price and per capita food consumption expenditure. The analysis is made at national level based on the application of the general equilibrium analysis (CGE).

This thesis will bear some limitations mainly for the reason that all micro economic determinants of food security at household level will not be assessed, inherently because of the methodology adopted as it is a general equilibrium analysis and thus the difficulty to represent all the micro economic factors in the SAM.

In addition, this paper will also borrow all the limitation of the micro econometric analysis of the effect of climate change on Ethiopian agriculture made by (Gebreegziabher, *et al.*, 2011), as all the scenarios about the impact of climate change on food security are taken from this article.

#### **1.6. Organization of the Paper**

The remaining part of the paper is developed in the outline where the second chapter reviews theoretical and empirical literature; the third chapter describes the methodology adopted and its specification in the context of the paper with detail lists of indicators for food security. In addition, the third chapter prevail all the climate scenarios adopted for productivity shock in the model and the data source. The fourth chapter discusses the simulation result framed with two categories from market supply and demand side. And the fifth chapter is the concluding and recommendation part.

## CHAPTER TWO

### Literature Review

#### 2.1. Theoretical Literature Review

##### 2.1.1. Food Security Concept and Definition, Indicators and Determinant Factors

There is no any single and a general working definition for food security; as the context and domain of food security differs in regions based on their institutional diversity, societal, economic and technological set up (Felix and Romuald, 2009). Thus, it is tried to summarize only two definition of food security in line with the interest of the paper.

*“FAO’s vision of a world without hunger is one in which most people are able, by themselves, to obtain the food they need for an active and healthy life, and where social safety nets ensure that those who lack resources still get enough to eat” (FAO, 2007).*

This definition of food security regards a resource or income that enables households to obtain food from market as the only determinant factor with the assumption that the world is unconstrained with food supply and hence food security is viewed globally. This vision has its roots in the definition of food security adopted at the World Food Summit (WFS) in November 1996:

*“Food security exists when all people at all times have physical or economic access to sufficient safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life” (FAO, 1996).*

(Barbolet, *et al.*, 2009) in a report for the Vancouver Food Policy Council defined food security in a general term with the consideration of its dynamism in coping and adopting a changing environment in all regards: institutionally, socially, environmentally, economically, and technologically.

*“Food security is achieved when the structure and capacity of the food system is resilient and adaptive and can meet the food related human, cultural, economic, social and environmental needs of the individual and community.”<sup>1</sup>*

But, the most working definition is the definition of food security developed by the United Nations Food and Agricultural Organization (FAO) in 1996:

This definition comprises the spiral of the four element of food security: food availability, stability, access and utilization. From FAO standard definition of food security, it can be inferred that food security comprises four key dimensions: availability, stability, access, and utilization.

Food availability is determined by the physical quantities of food that are produced, stored, processed, distributed and exchanged (FAO, 2008). Thus, food availability depends on domestic food production and imports (net). Hence any factor that underpins

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<sup>1</sup> Food system is defined in FAO’s frame work document as *“Food systems encompass (i) activities related to the production, processing, distribution, preparation and consumption of food; and (ii) the outcomes of these activities contributing to food security (food availability, with elements related to production, distribution and exchange; food access, with elements related to affordability, allocation and preference; and food use, with elements related to nutritional value, social value and food safety). The outcomes also contribute to environmental and other securities (e.g. income). Interactions between and within bio-geophysical and human environments influence both the activities and the outcomes”* (FAO, 2008).



production and import will also impact food availability. Micro indicators for food availability are domestic food price, household consumption and production level; whereas macro indicators will be import prices and world food supply (FAO, 2008).

Food access refers to a measure of the ability to secure entitlements, which are defined as the set of resources (including legal, political, economic and social) that an individual requires in obtaining food access (Sen, 1999). This definition for food access implies food availability alone is not sufficient to secure food. Though aggregate production is high in a country, food security might be challenged with access problem at household level to secure entitlement to food because of lack of resource virtually income. Entitlement to food is secured if all individuals have purchasing power (household income), and if there is market integration (role of distribution and information channels from food surplus area to shortage area). The indicators for food access, from the set of economic determinants, are per capita income and market integration level.

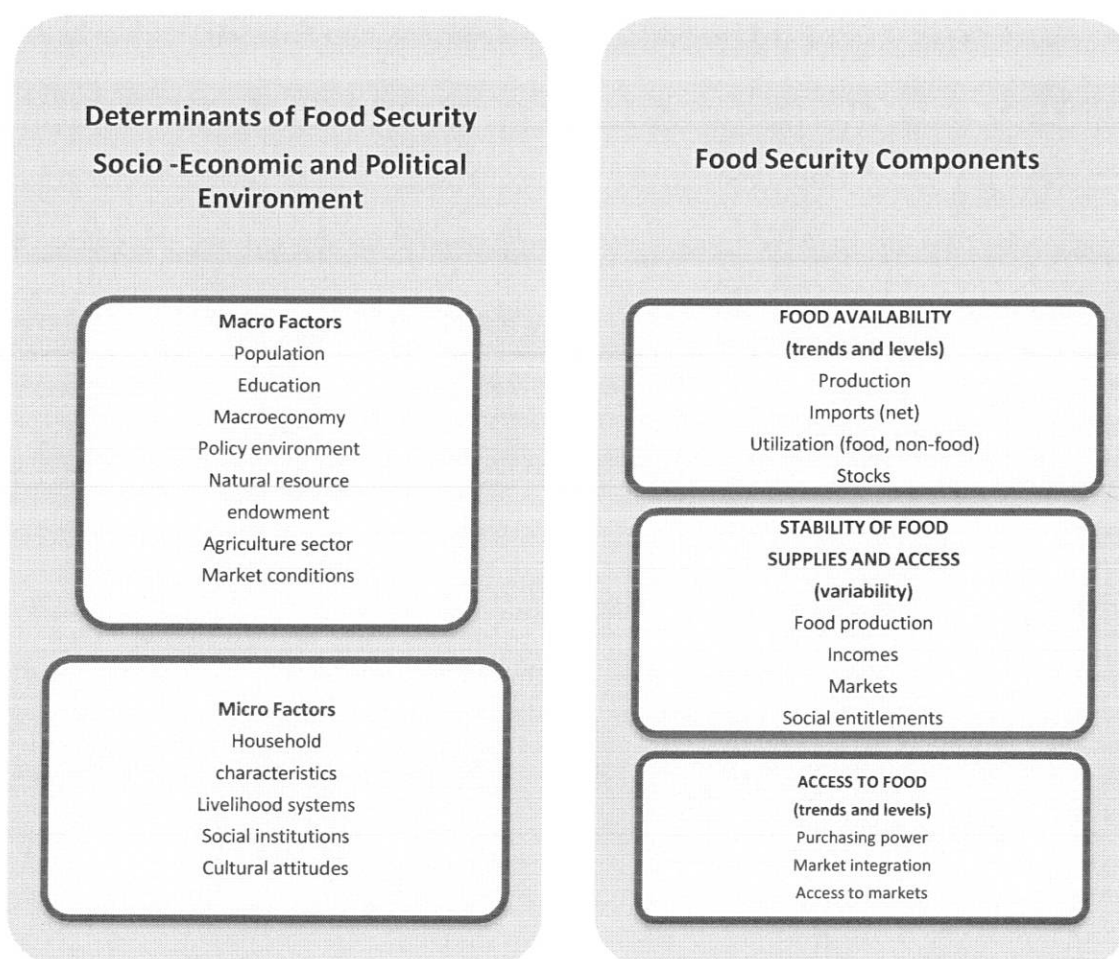
Stability refers to individuals who are at high risk of temporarily or permanently losing their access to the resources needed to consume adequate food (Felix and Romuald, 2009). It is determined by the temporal availability of and access to food. Thus, all the factors that affect food availability and access will also impinging on food stability.

Food use or utilization is justified based on the nutritional value of the food supplied to individuals. Nutritional value in this context does not exactly refer only to the biological content of the food but also the social value credited to the food based on local context, as

teff is for Ethiopia. If a food has no the required content of nutritional value, the individuals will be at risk of exposition to various diseases. These in turn will cape the physical and healthy capability of the individuals to work and earn enough resource in securing food access (FAO, 2008). This strand of food security is known to be affected by environmental factors mainly climate change.

Both micro and macro determinants are identified to constrain food security; where low rates of agricultural production, low access to food, infrastructure and local markets, and environment factors are micro determinants. Among the macro factors are economic performance, population growth, income inequality, and political regime (Felix and Romuald, 2009). The overall determinant factors are framed using the following diagram.

**Diagram 1: Food Security Components and Their determinants under socio-**



Source: (FAO, 2008)

As it is generally indicated in the previous diagram, food availability depends on the trend and levels of food production, food import<sup>2</sup>, and food utilization level including the stocks. Similarly, food stability is explained by the variability of food supply and access which are both depend on food production, incomes, market factors, virtually price and social entitlements. Moreover, food access depends on trend and levels of purchasing power in addition to food allocation, which bases on the structure and level of market integration.

<sup>2</sup> In the context of Ethiopia and all developing countries food import includes also food aid.

### **2.1.2. Effects of Climate Change on Food Security**

Climate change in IPCC usage refers to “*a change in the state of the climate that can be identified (e.g. using statistical tests) by changes in the mean and/or the variability of its properties that persists for an extended period, typically decades or longer. It refers to any change in climate over time, whether due to natural variability or as a result of human activity*” (IPCC, 2007a). This climatic variability will apparently affect the sector which mainly depends on natural resource; because it is pointed in IPCC synthesis report that many natural systems are being affected by regional climate changes. Agriculture in particular is most vulnerable to climate variability and hence food supply which pledges food security.

#### **2.1.2.1. Climate change effect on food availability**

Climate change constrains food availability in two ways. it directly affects food production as the result of land productivity and other natural input declining owing to the variability of climate. It also indirectly affects food availability through the change in some economic factors particularly income of household and technology set up to undertake agricultural activity. Climate changes are assumed to have effects through green house fertilization effect, rainfall, soil moisture, temperature and radiation variability effects (Leff, et al., 2004).

The green house fertilization effect is regarded to benefit temperate zones by stimulating plant growth from higher level of atmospheric CO<sub>2</sub> level; but this is particular only for temperate zones (FAO, 2008). But temperature variability is expected to have a different effect for different locations (Leff, *et al.*, 2004). For example, moderate warming (increases of 1 to 3 °C in mean temperature) is expected to benefit crop and pasture yields in temperate regions, while in tropical and seasonally dry regions it is likely to have negative impacts particularly for cereal crops. Warming of more than 3 °C is expected to have negative effects on production in all regions (IPCC, 2007b).

The effects of rainfall, soil moisture, temperature and radiation on crop yield depend on certain threshold of the set of the climate condition. If a variability beyond or below the threshold happened, crop yields will be negatively affected (Wheeler *et al.*, 2000). But the threshold level depends on the agro-ecological system of the location. Increased intensity and frequency of storms, altered hydrological cycles, and precipitation variance also have long-term implications on the viability of current world agro-ecosystems and future food availability (FAO, 2008). A study of (IPCC, 2007b) shows that the increases in mean temperature (6°C above long-term means) in European countries in 2003 led to a significant drop in crop yields. Generally, increased intensity and frequency of storms, altered hydrological cycles, and precipitation variance also have long-term implications on the viability of current world agro-ecosystems and future food availability (Felix and Romuald, 2009).



### 2.1.2.2. Climate change effect on food accessibility

Food access is economically described on the trend and levels of food allocation and affordability or purchasing power. Climate changes apparently constrain these two indicators directly and indirectly.

*Allocation:* food is allocated through market and non market mechanisms. The non market mechanisms include those farmers who produce food for their own consumption. In this circumstance, as climate change makes food production to decline, it may reduce availability to the point that allocation and consumption choices have to be made within members of the producing family (FAO, 2008).

Regarding food allocation through market mechanisms, it includes those household who acquire their food from market in exchange for money. Even though the households may have enough money to buy the food they intend to consume, there may not be enough food supply. Because food supply in the market may reduce as food production will decline inherently as the result of climate change (FAO, 2008).

*Affordability:* Generally, all preferred food is not produced by individual households but acquired through buying, trading and borrowing (Du and Ziervogel, 2004). On this instance climate change will affect the purchasing power of individuals in two ways. First, because of climate change, national food yield will decline triggering food price to go up thus challenging the purchasing capacity of households. An increase in food prices has a real income effect, with low-income households often suffering most, as they tend

to devote larger shares of their incomes to food than higher-income households do (Thomsen and Metz, 1998). High prices may make certain socially preferred foods unaffordable and will have an impact on individuals' nutrition and health.

Second, climate change will affect the income of individuals who are rendering their food demand through purchasing from market. As production dwindles because of the effect of climate change, demand for labor will decline which will make the market wage to decrease for farm labors (Felix and Romuald, 2009).

#### **2.1.2.3. Climate change effect on food stability**

As tried to discuss in the above diagram food stability is verified based on the temporal variability of food supply and food access. The food supply variability depends on food production cycle which in turn seasonally depends on climate variability. Hence any temporal climate variability, like cyclones, floods, and droughts results in greater fluctuations in crop yields and local food supplies which lead to a food stability problem. Rural households whose life depends on rain fed agriculture are highly vulnerable to this problem (FAO, 2008). In semiarid areas, the effect of climate fluctuations on food production is more severe because droughts can dramatically reduce crop yields and livestock size and productivity (IPCC, 2001).

Concerning the stability of food access, it is already discussed that food access depends on food allocation and purchasing power, which are all constrained by food production,

food price, and income of households. Hence a climate change causing variability to these factors will also be credited to matter food stability (FAO, 2008).

#### **2.1.2.4. Climate change effect on utilization of food**

Generally it is known that climate change impacts the food use or utilization trend of households. Food utilization refers to the nutritional value of the food availed for households. Nutritional content of a food can vary as the result of a change in environmental condition, which imposes an alteration in the photosynthesis process of plants (Rosenzweig and Binswanger, 1993).

Climate change will also affect the micronutrient content of a food in the way that it renders a favorable condition for revival and expansion of new plant and animal diseases. Even new diseases that attack human will be inborn as the result of climate change; typical to this is malaria. These diseases are lowering people's capacity to utilize food effectively and often resulting in the need for improved nutritional intake (McMchael, *et al.*, 2006). In addition, climate change can shape the decisions of farmers regarding the type of crops to cultivate as adaptation strategy; may be in case they will tend to stop cultivation of socially preferred crop for food. This happened mainly at the result of climate change, food price gets higher and become unbearable with the limited purchasing power of households especially for socially highly valued food items. Then, households will tend to abandon their tradition and starts to adopt new crop system and

the crop type in resisting climate change. This makes households to forgo their socially valued crop or food (FAO, 2008).

### ***2.1.3. Study approach and methods***

There are different methodologies and approaches used to assess the impact of climate change on an economy. Broadly the methodologies are categorized as “agriculturally oriented” and “economically oriented” researches. The agricultural oriented approach concentrates on the ecological and biological response of soils and crops to climatic variation, considering economic interactions only partially and in a very simplified form. The economically oriented approach emphasizes on market mechanisms by assuming agriculture as an industry part of the economic system necessarily oversimplifying the natural mechanisms at the base of crop growth and reaction to climate change ( Bosello and Zhang, 2005).

In spite of the broad categories mentioned above, the most known models used to analyze climate change impact on an economy are again identified as partial equilibrium analysis models and general equilibrium analysis model based on the scope that the models are dealing with. Partial equilibrium models depict part of an overall economy, assuming that industries have little effects on each other or the rest of the economy. General equilibrium models look at the economy as a complete, interdependent system, thereby providing an economy-wide prospective analysis capturing links between agriculture and non-agriculture sectors (Zhaif, *et al.*, 2009).

### 2.1.3.1. Partial equilibrium Approach

The partial equilibrium analyses are classified into three basic approaches: crop simulation models, agro-ecological zone (AEZ) models, and Ricardian models. Crop simulation models are used on controlled experiments where crops are grown in field or laboratory settings that simulate different climates and levels of CO<sub>2</sub> in order to estimate yield responses of a specific crop variety to certain climates and other variables (Zhaif, *et al.*, 2009). On (Mendelsohn and Dinar, 1999), it has portrayed that the crop simulation model do not include the effects of farmer adaptation to changing climate conditions. Consequently, their results tend to overstate the damages of climate change to agricultural production.

The AEZ model accounts for all factors addressed by the crop simulation model. In addition, it gives a great credit to land and land related factors and its management where their changes are considered as changes of climate resources (Darwin, *et al.*, 1995), and (Fischer, *et al.*, 2005). In this model, available land in a country are differentiated in to different AEZs based on their difference of length of growing period of crops (defined based on temperature, precipitation, soil characteristics, and topography) and other climate disparities. The effect of climatic change variability on crop production and the effect distribution across different zones can be captured using this model. This model is also used to simulate or predict the maximum production capacity of a land for climate changes under some set of management and controlled conditions (Zhaif, *et al.*, 2009).

Nonetheless, this model is claimed to suffer for a problem of over estimating or wrongly predicting the maximum production capacity of land in different AEZs as it does not account for farmers' adaptation to climate change explicitly (Cline, 1996).

The Ricardian approach is a cross sectional analysis used to deal with the effect of environmental factors including climate variables on farm income considered as proxy to land rent. The Ricardian model enables to account for farmers' adaptation to climatic change in affecting productivity. This model is extensively applied in many countries. In Ethiopia it has applied by many researchers (Temesgen, 2007, Meseret, 2009, and Zenebe, *et al.*, 2011).

This model is criticized on three grounds: first it is not based on a fully controlled experiment thus uncertainty about the probable effect of excluded factors in the model (Mendelsohn and Dinar, 1999) and (Cline, 1996). Second, it does not account for price changes and it fails to fully control the impact of other variables that affect farm incomes (Mendelsohn and Dinar 1999) and (Cline, 1996). Third, it is failed to account for the carbon fertilization effect (Mendelshon and Tiwari, 2000).

All the partial equilibrium analyses are under taken at a micro level and do not allow to make an economy wide analysis. It is strongly argued that food security problem should be analyzed at a nation level or if possible at a global level as a country's food supply does not depend only on domestic food production but also imported food. Based on this argument, it is presumed that partial equilibrium analysis is not appropriate to deal with

food security problem. In addition, the Crop simulation and the AEZ model do not consider the economic factors and the human capital in determining farm output (Mendelsohn and Dinar, 1999). These two models are not enabling to account for market factor which are very crucial to determine food security. The Ricardian approach can also discredited for the same reason as it does not consider all the economic factors.

### **2.1.3.2. The General Equilibrium Methodology**

This approach investigates the plausible effect of climate change on an economy and assesses the spillover of the effect in each economic sectors described by behavioral and economic equations. Climate change may affect various sectors of the economy directly or indirectly. Thus, interactions between different sectors must be studied to assess the impacts of climate change on agriculture. CGE models are well suited to depict interactions between agriculture and other sectors in the economy (Zhaif, *et al.*, 2009).

The general equilibrium analysis is based on the central idea of Pareto optimal allocation of resources within an economy (Whalley, 1986). It is used to computationally solve system of behavioral equations used to represent an economy of a nation or perhaps a globe with an objective of optimal resource allocation (Thomas, 1999). It focuses heavily on questions of model specification, parameter choice, and the appropriate representation of policies (Whalley, 1986). CGE models have long been popular in policy analysis, particularly to evaluate economy-wide and distributional welfare effects of economic changes in both developed and developing countries; and more recently, CGE models have been applied to analyze the impacts of climate change (Jesper, *et al.*, 2011).

CGE is used to analyze not only economic activity but also environment issues. Some environment research issues with application of CGE are the relationship between environment and economy, provision of services and goods, assimilation of pollutants, degradation of environmental quality, and environmental adaptation and maintenance (Toshihiko, 2005).

Two broad approaches have been used to assess impacts of climate change on agriculture within the CGE framework. The first approach is to develop an integrated assessment model, which couples a CGE model with a partial equilibrium agricultural land use model. The second approach is to improve modeling of land as endogenous within the CGE framework itself. Of the two approaches, the more common and simpler method is making land use allocation endogenous in a CGE model by improving the functional form within the CGE framework through a constant elasticity of transformation function. Early studies of this type usually treated land as homogenous, ignoring biophysical characteristics of land and spatial interactions. To overcome this limitation, some studies used a constant elasticity of substitution (CES) aggregated function to distinguish between different uses of land (Zhaif, *et al.*, 2009).

Another way to introduce heterogeneity of land within a CGE model is to classify land types by regional and climatic differences through an AEZ approach. One of the studies that took this approach is (Darwin, *et al.*, 1995), who evaluated impacts of global climate change on world agriculture using a future agriculture resource model made up of a

geographic information system and a CGE model. In their analysis, they disaggregated land into six classes differentiated by the length of growing season for eight regions of the world and 11 sectors. Similarly the IFPRI standard 2009 based CGE model of Ethiopia is developed on classification of regions in to four AEZs. While the above studies attempted to introduce land heterogeneity within the CGE framework, other research combined the CGE with partial equilibrium models. In consideration of all these features and advantages of CGE model, it has adopted as a methodology to this thesis in dealing with the impact of climate change on food security and food market at a country level.

## **2.2. Empirical Literature Review**

Recently the issue of climate change and its impact on the global and regions is getting an emphasis by many researchers. Different empirical literatures are reviewed here to show get bench mark in identifying the point of departure and or confirming the consistence of the finding for this thesis.

(Nelson, *et al.*, 2010) with the premise that neither food security nor climate change should be viewed in isolation, it has dealt on the effect of climate change on food security in the world. It asserts that CC coupled with recent food price hike in the world, population growth and hence increased food demand will pressure the world 's economy in the coming decades to 2050. The paper has used both the partial equilibrium analysis model and the Globe computable General equilibrium model to adress its research

questions. In the scenario of the paper, economic, population and climate change impacts are combined together. In analysing the food security impact of climate change, It has focused on three indicators: the prices of the most important crops (maize, rice, and wheat); the average daily kilocalories (kcal) consumed; and the number of malnourished children under five.

In the study it has found that the world food price shows substantial increases between 2010 and 2050. The price increasing varies from 31.2 percent for rice in the optimistic scenario to 100.7 percent for maize in the pessimistic scenario. In particular wheat price which is typical import food item for Ethiopia, increases with 23.4% in the optimistic scenario and with 24.4% in the pessimistic scenario. In justifying the result for the world food price change the paper has estimated the crop yield growth and land area usage changes. It has estimated yield growth ranges from a low of 0.25 percent per annum (developed country maize with climate change and the optimistic scenario) to a high of 1.88 percent per annum (wheat in low-income developing countries with perfect mitigation and the pessimistic scenario). Regarding land area usage, it shows a decline trend for developed nations (9-13%), but a dramatic farming land expansion for developing countries (18-25%). In combination the two factors are assumed to give production change where by the paper has affirmed rice and wheat production growth rate decreases everywhere with climate change compared with perfect mitigation.

With regard to the impact on consumption and calori intake, the paper has found that the number of malnourished children in low income countries will increase in 2050 by 9.8% with the optimistic scenario and 8.7% with the pessimistic scenario of climate change. However, the daily kilocalori available shows positive growth with climate change but

less than the case with perfect mitigation scenario. In conclusion, the paper argues that the challenge of reaching sustainable food security and delivering on it through 2050 is daunting by two looming challenges: growing world population and increasingly negative productivity effects from climate change. Especially climate change acts as a threat multiplier, making the challenges of sustainable food security much more difficult.

(Bosello and Zhang, 2005) also devotes on estimating the impact of climate change on agriculture in the world based on the a static general equilibrium analysis with formulation of a standard multi-country world CGE model: the GTAP mode (Global Trade Analysis and Policy Model) up to 2050. In the simulation the paper induced climate change impact as land productivity shock. It has found that for developing country GDP declines by 12.6% compared with the base line of no climate change. Regarding food price it has also reaffirmed that it will increase with climate change. Price for wheat will increase by 91.1% in developing countries (referred as RoW in the paper). In the last the paper has concluded that agricultural sectors in the developing world will be adversely affected with negative consequences either in terms of food availability or of welfare.

(Mendelsohn, *et al.*, 2000) with the objective of filling the knowledge gap on quantitative scaling of the impact of CC on africa's agriculture, it has applied a simulation analysis using a climatic scenario taken from IPCC forecast of future atmospheric carbon dioxide levels by 2100. The scenario is inputed to make impact analysis using GIM (Global Impact Analysis Model). According to this paper, the impacts in Africa ranges from a potential loss of \$25 billion to a loss of \$194 billion per

year, depending on the climate sensitivity used. In general the paper has computed that the damage from climate change to African agriculture is expected to range from 0.13% to 2% loss of GDP by 2100. In regional wise, the paper find that every region in Africa will experience some negative climate change impacts, but some regions will be more vulnerable to warming than others. The Sahara and EGAD regions are the most vulnerable with high percentage loss of GDP. Based on the cross-sectional climate response function estimation, the EGAD region where Ethiopia is found, losses around 10% of their agricultural value. This conveys that as the agricultural sector is the main contributor of food production, these negative effect of climate change on this sector rchallenges the food security situation in Africa .

Similarly, (Rashid, 2008), on his artcile is intended to probe how climate change (CC) has shaped African agriculture in the past, how it might impact African farm economies in the future, and what adaptation strategies African farmers need to implement. In the result, it has shown that African agriculture and the welfare of its rural population are vulnerable to CC. The highest risk of future CC damages is associated with specialised crop and livestock farming (mono systems) particularly under dryland conditions in arid and semi-aridregions.

Most importantly the work of ( Ringler, *et al.*, 2010) uses a comprehensive climate scenrio (CCC) based on ensembles of 17 GCMs (Genral Circulation Models) to assess the effects of climate change on food security of sub Saharan African countries. The paper has found that crope yeild decreases for all items except for millet and sorghum. Wheat exhibited the largest negative yield decline (-22%) followed by sweet potato. Concering food demand, the paper has found that under climate change, aggregate food demand for

cereals in the Sub-Saharan region will decline by 1.5 percent in 2050. Similarly food price is found to be higher than otherwise would be without climate change. Under climate change, maize, rice, and wheat price in 2050 is 4, 7, and 15 percent higher than in the historic climate scenario. This triggers an additional problem in worsening the food security problem in this region as households are losing their purchasing power from higher price. With the impact of child malnutrition, the paper revealed that per capita calorie availability across Sub-Saharan Africa declines by 1.3 percent or 37 kilocalories per capita per day. This is justified from the reason that households are becoming less capable of affording the higher food price and hence less food utilization. With these all findings the paper calls for a policy consideration of climate change in Sub-Saharan Africa.

Apart from these empirical works reviewed, a number of papers have been made on regional and country bases, some are: (Butt, *et al.*, 2005) in Mali, (Nhemachena, *et al.*, 2010) in South Africa, (Ernest, 2002) in Cameroon, (Mintewab, *et al.*, 2010) in Tanzania are few whose research theme is climate change and its impact on agriculture and the implication for food security.

Respective of the effect of climate change on agriculture production and hence food availability in Ethiopia, different partial and general equilibrium analysis and studies have been made. All the studies agree that climate change on an annual basis will decrease agricultural productivity in the country. (Temesgen and Hassan, 2009), (Meseret, 2009), (Zenebe, *et al.*, 2011), and (Yun and Ringler, 2010) are some empirical based on partial

equilibrium analysis. Whereas (Jesper, *et al.*, 2011) is the only work resort on general equilibrium analysis.

(Temesgen and Hassan, 2009), has applied the Recardian model to analyze the effect of climate change on crop production in Ethiopia. The estimation based on the long run temperature and precipitation change. The seasonal marginal impact analysis indicates that marginally increasing of the annual temperature reduces the net revenue per hectare by US\$ 21.61. Increasing precipitation during spring increases the net revenue per hectare by US\$225.08; whereas increasing precipitation during winter significantly reduces the net revenue by US\$464.76. Marginally increasing precipitation during summer and the fall also reduces the net revenue per hectare by US\$18.88 and US\$64.19, respectively. An increasing precipitation annually is reported to decrease net revenue per hectare.

In addition, the paper also simulated net crop revenue impact of predicted climate scenarios from three models (CGCM2, HaDCM3 and PCM) for the years 2050 and 2100. The result indicates that there would be a reduction in crop net revenue per hectare by the years 2050 and 2100<sup>3</sup>. This implies that CC intensifies the food security problem of the country at least from the availability side as agricultural revenue per hectare has declined with climate change jointly for both annual increasing of temperature and precipitation reported in the finding.

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<sup>3</sup> The model estimation of the work of (Gebreegziabher Z., *et al.*, 2011) regarding the marginal effect of long run temperature and precipitation change, and the simulated result about the net revenue impact based on predicted climate scenario of CGM2, HaDCM3 and PCM for the year 2050 and 2100 can be referred on Table 6 pp 541, and Table 10 pp 546 respectively.

(Meseret, 2009), in his thesis, with Recardian model also indicates that increasing temperature and decreasing rain fall as a subset of a change in climate significantly damages crop production in Ethiopia especially for dry land farming. A consisted result with findings of (Temesgen, and Hassan, 2009) which shows a decline in food production with climate change.

In the policy discussion paper of IFPRI, it is also identified that frequent hydrologic event is found to be the major factor of climate change influencing the economy of the country by causing both the agricultural and non agricultural sector to loss its output (Yun and Ringler, 2010).

On the other hand (Jesper, *et al.*, 2011) has adopted a genral equilibrium analysis model to investigate the economy wide imapct of climate change in ethiopia using a dynamic CGE model calibrated with IFPRI SAM for Ethiopia. They have used two projection of TFP 0% and 2.6% shocked with a decreased in land productivity as a result of climate change. The scenario is taken from the Recardian estimation of agricultural profit impact of CC reviewed from (Zenebe, *et al.*, 2011). In the analysis, the paper has focused on the change in crope and livestock production of the dominant agroecologies of agricultural production in the country: moisture sufficient highland cereal based and the drought prone area. In the report of the finding, it has portrayed graphically that crope and livestock prodction in the moisture sufficient highland declines after 2030 with climate change. It means this region has a grace period of production increment up to 2030 when

land productivity declining is projected to start. Where as, for the draought prone area crop production is projected to decline after 2050; and the livestock production starts to decline in 2030 but shows increasing trend after 2050. However for all regions, level of production of crop and livestock with climate change is projected to be less than it would be otherwise without climate change. Similarly CC found to affect incomes of all household group. Per cpita income in no TFP consideration shows a 30 percent loss with climate change compared with no climate change. The paper in bold has concluded that despite of the level of CC effect, TFP growth will reverse the effect and enables rather the economy to exhibit a positive growth in all macro indicators atleast up to 2030<sup>4</sup>. All the emperical findings reviwed at global, continental and country level are agreed that climate change in low income country is looming the food security problem.

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<sup>4</sup> Refer (Jesper, *et al.*, 2011) for all simulation results from pp 12-14, Fig1, Fig2, Fig3, Fig4, Fig5, & Fig6.

## CHAPTER THREE

### Methodology and Model Specification

#### 3.1. Methodology

In studying the effect of climate change induced productivity change on food market and food security, a recursive dynamic CGE model version II based on the Ethiopian IFPRI standard model is employed. Climate change is assumed to affect the productivity the agriculture sector and then the effect will be transmitted in impacting the food security and the food market. With the fact that agriculture is the major sector in the economy of Ethiopia where the other sectors depend on for their input source, any change in this sector will have a spillover effect on all other sectors. To this regard the CGE modeling is preferred to make an analysis of sectoral linkages (Xinshen, *et al.*, 2011).

The CGE model used in this analysis follows the neo-classical structure as it was first presented by (Devis, *et al.*, 1982). Particularly in this thesis, indicators for food availability and stability, food access, and food utilization (nutrition) are included in the price, production, and institutional blocks.

The data framework for this CGE simulation study is the 2009 standard SAM for Ethiopia developed by the Ethiopian Development Research Institute (EDRI) in collaboration with Institute of Development Studies in the University of Sussex.

In the structural equations of the model, there are four Bloks: the production and trade block, the price block, the institutional block, and the system constraint block. For all

blocks, the closure is specified based on the theory and the empirical context of the issues. Apart from specifying the closure and the equation type, three specific equations as indicators of the four components of food security is specified and incorporated in the standard model of CGE.

One of the indicators is per capita food production from the market supply side used to denote the per capita food availability and stability. The other two indicators are per capita GDP and per capita food consumption expenditure from the market demand side and are used to describe the food access, stability and utilization. The per capita food availability will be determined by total food production and population, while the per capita GDP will be determined by total GDP and population (Wu, *et al.*, 2010).

The change in per capita food production is assessed by comparing the per capita food production in the targeted year  $t_s$  with the baseline year  $t_b$ . Change ratio of per capita food production ( $CR_p$ ) calculated with the following Equation.

$$CR_p = \frac{\sum_{i=1}^n Y_i^{t_s} * A_i^{t_s} / POP^{t_s}}{\sum_{i=1}^n Y_i^{t_b} * A_i^{t_b} / POP^{t_b}} \quad \text{----- (1)}$$

Where

$CR_p$  is the ratio of the per capita food availability of the simulation with the base;

$Y$  is the crop yield for crop type  $i$ ;

$A$  is the crop areas for crop type  $i$ ;

$POP$  is the total population;  $n$  is the total number of crops.



Secondly, in investigating the food access and stability problem from measurement of allocation and purchasing power of households, the ratio of per capita real GDP of the climate scenario with the base line will be appraised. If per capita real GDP ratio becomes more than one, it implies purchasing power of households or the nation grows even under climate stress and better food access in result. If per capita real GDP ratio becomes less than one, it signifies a distressing food access mounting food security problem under climate change (Wu W., *et al*, 2010).

$$PERCGDPG_P = \frac{PERCGDPG^{ts}}{PERCGDPG^{tb}} \text{-----} (2)$$

Where,  $PERCGDPG_P$  ratio of per capita real GDP for simulated period compared with the base line.

In a similar fashion, the per capita food consumption expenditure in real is analyzed as a ratio of the climate scenario to the base. Again a deviation above and below one is analyzed as increasing and decreasing trend of food consumption expenditure from the base implying an improved or deteriorated food access, stability and utilization.

$$FEH_{h_P} = \frac{FE_{Ps}}{FE_{Pb}} \text{-----} (3)$$

Where  $FEH_{h_P}$  is per capita food consumption expenditure ratio,  $FE_{Ps}$  is per capita food consumption expenditure with climate change, and  $FE_{Pb}$  is per capita food consumption expenditure for the base scenario.

### 3.2. Model Specification

The model for this paper is specified in the manner that the above equation will be adopted and described under the appropriate blocks of the standard CGE model. Since all the figures in the SAM are in monetary value, the CR value will be defined as:

$$CR^a_{-p} = \frac{\sum_{a=1}^n QA_a^{t_s} / POP^{t_s}}{\sum_{a=1}^n QA_a^{t_b} / POP^{t_b}} \quad \text{-----} \quad (4)$$

Where  $CR^a_{-p}$  is ratio of real values of production for activity a (crop a) in the simulated year  $t_b$  compared with the base year  $t_s$ ,  $QA_a$  is real values of production in activity a, POP is population.

Similarly the real per capita GDP ratio as indicator of the food access is computed using the formula: In the CGE model GDP is computed as aggregation of value added:

$$GDP = QVA_a = \alpha_a^{va} \cdot (\sum_{f \in F} \delta_{fa}^{va} \cdot QF_{fa}^{-\rho_a^{va}})^{\frac{1}{\rho_a^{va}}}$$

Where  $QVA_a$  is aggregate value added;  $\alpha_a^{va}$  is efficiency parameter in the CES value-added function;  $\delta_{fa}^{va}$  CES value-added function share parameter for factor f in activity a;  $\rho_a^{va}$  CES value-added function exponent;  $QF_{fa}$  where  $f \in F(F')$  implies a set of factors.

Real per capita income for the country is therefore obtained as.

$$PERCGDP_{-P} = \frac{QVA_a^{ts} / POP^{ts}}{QVA_a^{tb} / POP^{tb}} \text{-----} (5)$$

This formula is adopted and described in the production and trade block of the CGE model. As described above, the implication of the output will be, if the average per capita income over simulated periods with climate scenario is less than the average of per capita income of the base, it implies that people in that nation are losing their their income with climate change.

Per capita food consumption is used as indicator for food access in addition to the per capita income. The per capita food consumption expenditure is labeled in the institutional block of the CGE model. It is specified as:

$$EH_h = (1 - \sum_{i \in INSDNG} shii_{ih}). (1 - MPS_h). (1 - \overline{tins_h}). YI_h \quad h \in H \text{----} (6)$$

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. This expenditure function is a linear function of household income. From the above equation the per capita food consumption expenditure ratio is computed as:

$$FEH_{h-P} = \frac{\sum_{i=1}^n shr_f EH_h^{ts} / POP^{ts}}{\sum_{i=1}^n shr_f EH_h^{tb} / POP^{tb}} \text{-----} (7)$$

Where  $FEH_{h-p}$  is per capita food consumption expenditure ratio of the climate change scenario to the base without climate change,  $shr_f EH_h$  is the total food consumption expenditure,  $Shr_f$  is the share parameter for food expenditure from the total household expenditure. Again the ratio less 1 is interpreted as the household are spending less on food with climate change compared with the base year.

### 3.3. Price Block

. Domestic food supply price change is also used to indicate the food access and availability problem. The price block consists of equations in which endogenous model prices are linked to other prices (endogenous or exogenous) and to non price model variables (Lofgren, *et al.*, 2002). But here only price of a commodity supplied will be defined from total activity price.

$$PA_a = \sum_{c \in C} PXAC_{ac} \theta_{ac} \quad \text{-----} \quad (8)$$

Where

$a \in A$  = a set of activities,

$PA_a$  = activity price (gross revenue per activity unit),

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

$\theta_{ac}$  = yield of output  $c$  per unit of activity  $a$ .

The gross revenue per activity unit, the activity price, is the return from selling the output or outputs of the activity, defined as yields per activity unit multiplied by activity-specific

commodity prices, summed over all commodities. This allows for the fact that activities may produce multiple commodities.

Given the gross price of an activity, what is important for the analysis of this paper with regard to food access, availability and stability is the specific food price in the agricultural activity, i.e.,  $PXAC_{ac}$  producer price of commodity specifically for food commodities. In the thesis the percentage change of food supply prices of major crops is analyzed to infer about the allocation or availability, and affordability of domestically produced food.

### **3.4. Production and Trade Block**

Production is carried out by activities that are assumed to maximize profits subject to their technology, taking prices (for their outputs, intermediate inputs, and factors) as given (Lofgren, *et al.*, 2002).

A constant elasticity substitution activity production function is adopted for this paper, with the assumption that all the inputs for the agricultural production are imperfect substitutes. Value added is modeled using constant elasticity of substitution (CES) production functions of factor inputs (land, livestock capital, various types of labor and non-agricultural capital). Intermediate inputs are also determined as fixed shares of the quantity of output.

A quantity of output in an activity in the CGE model is determined using the equation:

$$QA_a = \alpha_a^a \left( \delta_a^a \cdot QVA_a^{-\rho_a^a} + (1 - \delta_a^a) \cdot QINTA_a^{-\rho_a^a} \right)^{\frac{1}{\rho_a^a}}, \quad a \in ACES \quad \text{----- (9)}$$

Where,  $QA_a$  is quantities of production in activity A;  $QVA_a$  is quantities of (aggregated) value added;  $QINT_a$  is quantities of aggregated intermediate input in activity A;  $\alpha_a^a$  is efficiency parameter in CES activity function;  $\delta_a^a$  is CES activity function share parameter;  $\rho_a^a$  is CES production exponent; and the notation  $a \in ACES$  is to imply that activity production function is a CES at the top of the technology nest.

On top of this equation, for this thesis particularly a per capita food production level is used as indicator of food availability.

$$CR^a_{-P} = \frac{\sum_{a=1}^n QA_a^{t_2} / POP^{t_2}}{\sum_{a=1}^n QA_a^{t_1} / POP^{t_1}} \quad \text{----- (10)}$$

With regard to the trade column, imported goods are assumed to be imperfect substitutes for domestically produced goods; likewise, exported goods are imperfect substitutes for domestically produced and consumed goods.

### 3.5. Institutional Block

#### 3.5.1. Incomes and Consumption

Payments from each factor of production will be allocated to households and other institutions using fixed shares derived from the base SAM. Household consumption is modeled using a Linear Expenditure System (LES) specification described in equation 6.

$$EH_h = (1 - \sum_{i \in INSDNG} shi_{ih}). (1 - MPS_h). (1 - \overline{tms}_h). YI_h \quad h \in H$$

The label of the variables are defined above in equation 6, and consumption expenditure is computed as net of household income by deducting income transfer to the other institution from the household, saving and tax. Extending this equation, a per capita food consumption expenditure ratio is used as indicators of food access and utilization problem. It is defined in equation 7 as:

$$FEH_{h-p} = \frac{\sum_{i=1}^n shr_{fEH_h}^{ts} / POP^{ts}}{\sum_{i=1}^n shr_{fEH_h}^{tb} / POP^{tb}}$$

A ratio less than one will be interpreted as less food expenditure during climate change compared with the base without climate change. For a ratio greater than one, it indicates an increase in food consumption expenditure and hence better food access and utilization.

### 3.6. System Constraint Block and Assumptions



The model closure of each market is governed as:

- In the commodity markets prices adjust to equate supply and demand
- In capital market (including livestock capital), it is assumed to be fixed by sector and region or assumed to be activity specific but fully employed.
- Land is fixed by region, but is mobile across crops and fully employed.
- In labor markets total supply of labor of each skill type is fixed, fully employed, mobile and real wages adjust so that demand for labor is equal to supply

Similarly the closures for macro balances are specified as:

- With regard to the trade balance, it is assumed as to have fixed foreign savings (foreign capital inflow), so trade balance (current account) is also fixed. Then, real exchange rate adjusts to achieve export supply and import demand that yield the fixed trade balance.
- In the absorption balance, it is assumed that aggregate investment, government demand, and consumption are fixed shares of total absorption. Any macro adjustment burden will be shared equally across macro aggregates. Furthermore, government deficit is endogenous.
- Saving driven investment closure is adopted as saving does not adjust to investment in Ethiopia's case, rather saving is exogenously fixed.
- Consumer price index numeraire is used; that is all price is determined relative to the fixed consumer price index.

- Furthermore the assumption for all exogenous parameters is adopted from the assumption of PASDEP for Ethiopia (Plan for Accelerated and Sustainable Development to End Poverty). In particular 3% population growth adopted (a World Bank estimation of median population growth rate for Ethiopia).

### 3.7. Scenario and Data Source

The scenario for the analysis of the CGE modeling is taken from the empirical literature written by (Zenebe, *et al.*, 2011). In the paper, net revenue of agriculture is assumed to be affected by climate variables such as temperature and precipitation, and socio-economic variables. The paper has estimated about the effect of climate change on net revenue for 2050 and 2100 based on three atmosphere ocean global circulation climate forecasting model namely CGCM2, PCM, and HadCM3<sup>5</sup> under A2 assumption of SRES.

The Recardian cross sectional estimation of net revenue change as the result of climate change is related with total factor productivity growth (TFP) under the assumption of perfect product and resource market. The proof is displayed in the appendix. Some manipulations is made to come up with the scenarios of climate change impact on TFP, in the first, the joint effect of temperature and precipitation on net revenue is computed from

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<sup>5</sup> . CGCM2 (Coupled global Climate Model) based on the A2 IPCC Special Report on Emission Scenario (SRES) assumption, projects temperature to increase from 21.25-24.55°C in 2050, whereas precipitation to decrease from 76.77-66.79; PCM (Parallel Climate model) projects temperature to increase from 21.25-23.55°C, and precipitation to increase from 76.77-66.79 in 2050; and HaDCM3 (The Hadley Center Coupled Model) also projects that temperature to increase from 21.25-25.05°C and precipitation increase from 76.7 -83.68 in 2050 (Gebreegziabher Z., *et al.*, 2011).

their marginal change and impact <sup>6</sup>. In the second, the simulated 50 years cumulative impact of temperature and precipitation on net revenue is discounted and manipulated to come up with a per year effect.

Table 1: TFP Scenario

Models	Crop	Livestock
PCM	-0.24%	-0.36%
HadCM3	-0.60%	-0.83%
CGCM2	-0.69%	-0.55%

Source: Self computed from the simulated result of CC impact on net revenue by (Gebreegziabher Z., *et al.*, 2011)

Pertaining to the data source, an IFPRI standard 2009 Ethiopian social accounting matrix is used as a data source. A Social Accounting Matrix (SAM) captures the complete relationship that links the income and expenditure of each category of economic agent in a given economy (Tebkew T., *et al.*, 2009). The SAM disaggregates agricultural activities, land and rural households by agro-ecological zone (AEZ). The four AEZs distinguished in the SAM differ in terms of climate, moisture regime and land use<sup>7</sup>.

The regional disaggregation of crop production for each activity is based on value shares derived from the Agricultural Sample Survey for 2005/06. The SAM distinguishes 118 activities, including 65 regionally differentiated agricultural activities belonging to 13 distinct agricultural activity groups and one aggregated forestry and fishing activity, 21

<sup>6</sup> The joint effect of both temperature and precipitation is obtained using differential calculus and the per year effect is obtained using a compound discounting formula. A per year impact of climate change on net revenue is calculated from the 50 years cumulative impact using the formula,  $r = (1 - p)^{1/50} - 1$ , where  $p$  is the percent by which net revenue changes over 50 years, and  $r$  is the rate by which net revenue changes per year.

<sup>7</sup> In the IFPRI standard CGE model for Ethiopia, the five agro-ecological zones distinguished are merged to be four where the moist sufficient high land inset based is included in the moist sufficient highland cereal based.

industrial activities and 12 service activities. It also accounts for 91 commodities that are broadly divided into marketed commodities and own-consumed commodities. The agricultural sector produces 25 marketed and 20 own-consumed commodities. The industry sector produces 30 marketed commodities and the service sector generates two own-consumed and 14 marketed service commodities. Factor income flows are recorded in 25 factor accounts. There are 14 household accounts, distinguishing rural households by income class in each of the four regional zones and urban households by income class and size of urban settlement.

## CHAPTER FOUR

### Simulations Result and Discussions

In the simulation of the impact of climate change on food security through agricultural productivity changes, estimation has been made up to 2035 starting from 2010 by considering 2009 as a base year.

#### 4.1. Supply Side Analysis

##### 4.1.1. Domestic Food Supply:/Food Availability: Per Capita Food Production<sup>8</sup> (Trend and Levels)

Food supply or availability is one of the major components of food security. Food availability is measured using annual per capita food production of the country. It is the trend and level of food production which matter to secure sustainable food availability. Per capita food production is compared for the three scenarios of climate change with the base line.

In Figure 1, it has shown that per capita food production continuously increases up to 2035 for all scenarios. The country has a longer grace period during which food production continues to increase even with climate change for two reasons. In the first, as the variability of the climate is increasing with time, the intensity of its impact on food production also increases. This is due to the reason that the productivity of the agriculture is not immediately deteriorated as the result of the climate change. The productivity decreases gradually as the effect and variability of the climate is increasing with time. In

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<sup>8</sup> The production value is converted to US dollar based on the current exchange rate of 2012.

the second, all the crops and the agro-ecological zones are not affected negatively by the climate change. However, average annual per capita food production over the simulation period shows that per capita food production under the base exceeds the production level under climate scenarios. Thus, there is a loss of food production with climate change when it is compared with the base without climate change.

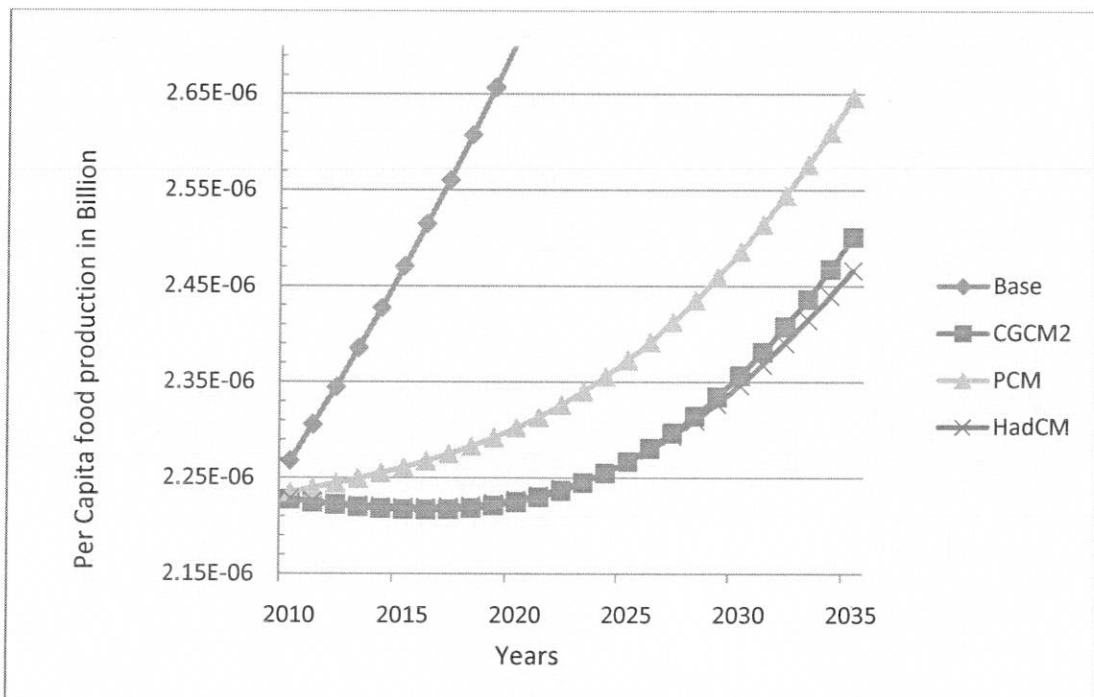


Figure 1: Trends of Per Capita Food Production in Bill.  
Source: Model simulation result from CGE

In Figure 1 it can be observed also that the HadCM3 climate projection results in pessimistic scenario with a large decline in food production. This can be observed from the per capita food production ratio ( $CR_p$ ) summarized in Table 2.

Table 2: Per Capita food production ratio of the simulation with the base line

Scenarios	CGCM2	PCM	HadCM3
CR_p	0.79239	0.82007	0.78893

Source: self computed from CGE result

The per capita food production ratio for all climate scenarios is less than one. This implies a loss of 20.9%, 18.01%, and 21.13% per capita food production under the CGCM2, PCM, and HadCM3 climate scenarios respectively on average over 25 years<sup>9</sup>. The reduction in the food production pertains to the negative TFP shock induced for the simulation.

This result can be evidenced more if the growth rate in yields of major cereals and livestock production namely: teff, barley, wheat, maize, cattle, milk and poultry is considered. As it can be seen from Figure 2 a negative elasticity of yield growth is observed for all cereal crops. Whereas, the livestock yields has shown negative yield growth elasticity under the CGCM2 and HaDCM3 climate scenarios but positive with the PCM climate scenario. Again the HadCM3 and CGCM2 climate projections exhibited around -0.4% yield growth elasticity for major cereals contrasting to the base where all cereals show above 1% yield growth elasticity. Similarly these two climate scenarios shows around -0.3% and -0.1% yield growth elasticity respectively for livestock production.

<sup>9</sup> Food production in this paper is an aggregation of all crop and animal productions.

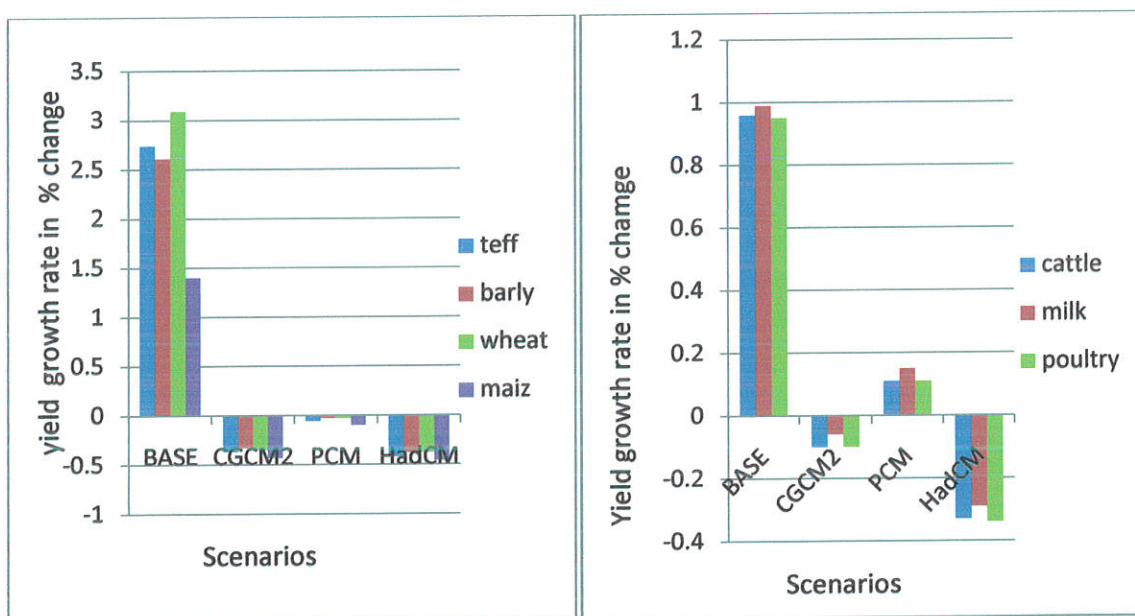


Figure 2: Percentage Changed of Yield Growth for Major Cereals and Livestock products  
Source: Simulation result from CGE Model

This negative yield growth for major cereals and livestock product implies that shortage of food availability in the country is a real challenge in the future with climate change.

Climate change has a different impact on the food availability across the agro-ecological zones. An interesting result is observed from Table 3 where the moisture sufficient highland cereal based area shows a decline in value added for all major cereals productions. In this region value added production for major cereals has decreased by more than 50% under all climate scenarios compared with the base. The same trend is observed for the drought prone area with 65-68% reduction of value added for all cereal production under all climate scenarios. Teff and barely production in this region shows rather a positive percentage change in their value added. But the region is known for high

production practice of maize and wheat than teff and barely. Thus, the decline in the quantities of value added production of maize and barley outweighs the increase in teff and barely production which makes the percentage changes of value added for all cereals in this region is negative. These two regions are the country's largest contributors of cereal production where there is much more crop production than livestock. Hence, the decline in cereal value added production in these regions with climate change will have a net negative impact for cereal production in the country overall. However in contrast to this, major cereal production in high land enset based and the pastoralist region shows a positive percentage change with more than a double increasing under all climate scenarios compared with the base. This is because these regions depend mainly on enset and livestock production thus less resource is deployed to cereal production. Hence, as coping mechanism to climate change by diversifying their income source, households in these regions tend to allocate their fixed land (by region and households) from their customarily farming practice to new. For instance, the highland enset based area is shifting their land from growing maize and wheat to teff and barley. Similarly, households in the pastoralist area shifts their time, labor and land resource from livestock production to crop plantation.

Table 3: Percentage changes of value added production for major cereals across agro-ecological zones under climate change

Agro zones	CGCM2	PCM	HadCM3
Moisture Sufficient high land cereal based	-53.58	-50.13	-54.01
High land enset based	183.05	198.21	177.71
Drought Prone	-68.07	-65.95	-68.32
pastoralist area	394.19	421.13	387.84

Source: simulation result and self computation

In contrast to the above finding in Table 3, quantities of value added production for major livestock products, such as cattle, milk, and poultry, shows a negative percentage change in the highland enset based and the pastoralist area. The moisture sufficient cereal based and the drought prone areas also exhibited negative percentage change of production in major livestock products. This analysis implies that households in all agro-ecological zones can decide to reallocate their fixed land and resources for alternative productions to cope with climate change.

Table 4: Percentage changes of value added production for major livestock products across agro-ecological zones under climate change

Agro zones	CGCM2	PCM	HadCM3
Moisture Sufficient high land cereal based	-24.95	-20.59	-29.62
High land enset based	-23.77	-19.48	-28.56
Drought Prone	-23.42	-19.01	-28.12
pastoralist area	-24.40	-19.93	-29.22

Source: simulation result and self computation

#### 4.1.2. Imported Food Supply

When there is food production decline domestically for environmental shocks, a country will resort to fill the food supply gap using imported food, purchased and aid. A typical imported food items by the country are wheat, pulses, other crops, processed dairy, imported poultry, and processed other foods.

As the trend shows in the simulation result, the percentage of imported food increases with climate change compared with the base. Imported wheat increases by 9.75% from with the base scenario from initial which becomes 11.91% with CGCM2 climate scenario, 12.01% with PCM, and 11.78% with HadCM3.

Table 5: percentage changes of imported foods (%)

Imported Food Items	BASE	CGCM2	PCM	HadCM3
Wheat	9.75	11.91	12.01	11.78
pulse	11.99	14.89	14.1	14.76
Other crops	13.05	15.83	15.18	15.67
Processed dairy	19.91	21.54	21.3	21.94
Processed other food	8	8.61	8.27	8.31
Processed poultry	10.76	11.85	11.62	12.37

Source: Simulation result from CGE

This result conveys that under climate change the country will become dependent on imported food than it would be without significant change in climate. This will make the country to be vulnerable or affected by any world food production and price shock. Perhaps how much the country will import to fill the food shortage depends on the purchasing power or income of the country. To this regard, under the market demand side analysis on Table 6 it has shown that per capita income is decreasing with climate change compared with the base. Therefore, the country will get a difficulty to finance its imported food. This makes the country to depend on food aid.

#### 4.1.3. Domestic Food supply price

Food price for domestic supply determines mainly the food access to households. It is expected that food price will rise as the result of the decline in food production because of climate change; and this will limit the purchasing power of the households and hence their food access. But it is more imperative to know which food item's price is increasing highly and under what climate scenario. To this information, the price change for major

cereals and livestock products is analyzed under the three climate scenarios (CGCM2, HaDCM3, and PCM).

In the base scenario, supply price for all major crops declines especially for wheat and teff with -1.5% and -2.8% respectively. In contrast to the base scenario, supply price for teff, barley, and maize raises under the climate scenarios by around 1.5% on average. Regarding the livestock price, all items have shown a positive and relatively large price changes compared with the cereals in all climate scenarios (2-3%). Again, the CGCM2 and HadCM3 climate scenarios results a greater impact than the PCM projection on food price. The food price increment coupled with the decline in per capita income of household will reduces their purchasing power and stressing the food access problem.

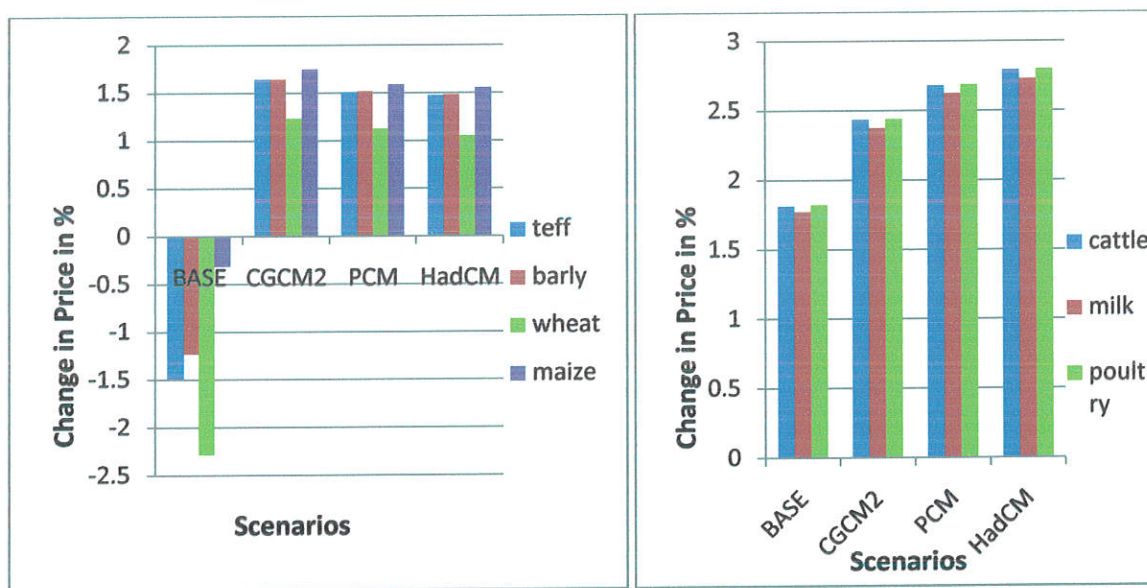


Figure 3: Percentage Changes of supply price for Major Crops and Livestock Products  
Source: simulation result with CGE model.



## **4.2. Demand Side Analysis**

The per capita income changes and per capita food consumption expenditures are discussed in analyzing the food access and stability problems. And finally household welfare changes based on the equivalent variation method is analyzed to imply for food security problem.

### **4.2.1. Food Access and Stability Problem from Purchasing Power Changes**

As the result of the shock in climate change, real per capita income which basically determines purchasing power declines for two reasons. In the first, when agricultural income falls because of production decline with negative yield growth elasticity for both crop and livestock for agricultural producers. In the second, from a loss in wage for farm employees as agricultural producers tend to reduce their labor when their production declines with climate change. In this situation, households will be challenged from a loss in their purchasing power and economic resources which matter their entitlement for food access. A decline in per capita income compared with the base line becomes a real problem if food price is assumed to be increasing throughout during the simulation period.

In Figure 4, it can be observed that per capita GDP tends to increase continuously up to 2035 in all scenarios. Even though the per capita GDP level increases for all climate scenarios, it lies below the base line. This figures out that a loss of per capita income with climate change compared with the base without climate change. The per capita income loss ranges on average from 6.3% under the optimistic PCM climate scenario to 8.5%

with the pessimistic HadCM3 climate scenario. Since food security depends on the physical and economic resources needed to get enough food for active and healthy life, both the reduction in food availability and income with climate change will be a challenge to the future for the country.

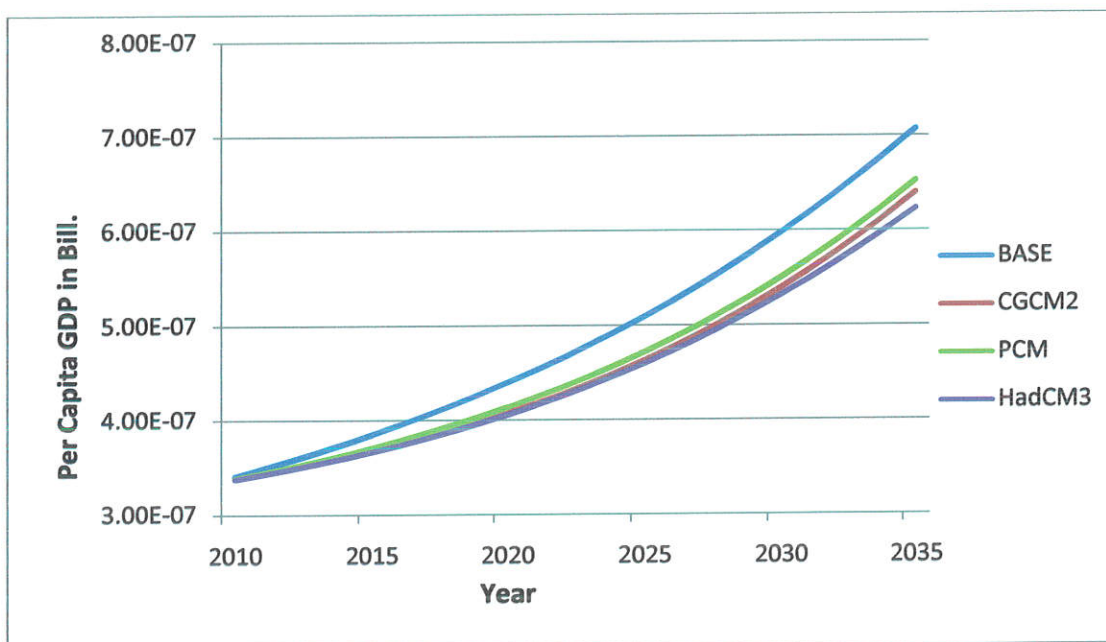


Figure 4: Per Capita GDP in Bill.<sup>10</sup>

Source: Simulation result with CGE model.

The per capita GDP ratio (PERCGDP\_p) of the climate scenario with the base is less than one. Where, under CGCM2, PCM, and HadCM3 climate scenario PERCGDP\_p is 0.922, 0.937, and 0.914 respectively. This implies a decline in income of household with climate change by 7.78%, 6.35%, and 8.62% respectively for the three climate scenarios.

<sup>10</sup> GDP value is converted to US dollar based the current exchange rate of 2012.

Table 6: Mean Per Capita GDP ratio of the climate scenarios with the base

PERCGDP_p	CGCM2	PCM	HadCM3
	0.922	0.937	0.914

Source: Self computed from CGE result

#### 4.2.2. Food Access problem from Food Consumption Expenditure

There is a premise which conveys that more food consumption implies more food access and utilization. Food consumption level depends on household expenditure. Therefore, it is analyzed the trend and levels of food consumption expenditures to discuss about food access under different climate scenarios. The trend in food expenditure is discussed on three categories, for national, urban and rural household.

##### 4.2.2.1. National Food Consumption Expenditure

Theoretically, it is known that consumption is a positive function of income. To this regard it has observed in Figure 4 that per capita income has increased throughout the simulation period for all climate scenarios but less than the base. Consisted to this trend, Figure 5 below prevails that per capita consumption has increased up to 2030 for all climate scenarios and starts to decline then after. This is true even for the base scenario. Probably thought that a period after 2030 is period of economic stagnation; or may be the negative effect of increased food price on consumption expenditure starts to outweigh the positive effect of increased per capita income.

In Figure 5, it can be viewed that per capita food consumption expenditure for all climate scenarios lies below the base where the HadCM3 hold to be the worst scenario. The per

capita food consumption expenditure ratio ( $FEP_{h_p}$ ) from the average of all simulations period as an index for food access is reviewed as:

Table 7: Per Capita Food consumption expenditure ratio ( $FEP_{h_p}$ )

$FEP_{h_p}$	CGCM2	PCM	HadCM3
	0.951031	0.971649	0.93556701

Source; Self computed

According to the  $FEP_{h_p}$  measurement, CGCM2 climate scenario results in 4.9% decline in food consumption expenditure; where under PCM it has declined by 2.8% and under HadCM3 by 6.4% compared with the base without climate change. This conveys the idea that climate change will make all the households with less food access and utilization level. The situation will be worsened after 2030 during which per capita food consumption expenditure will even decline in its level.

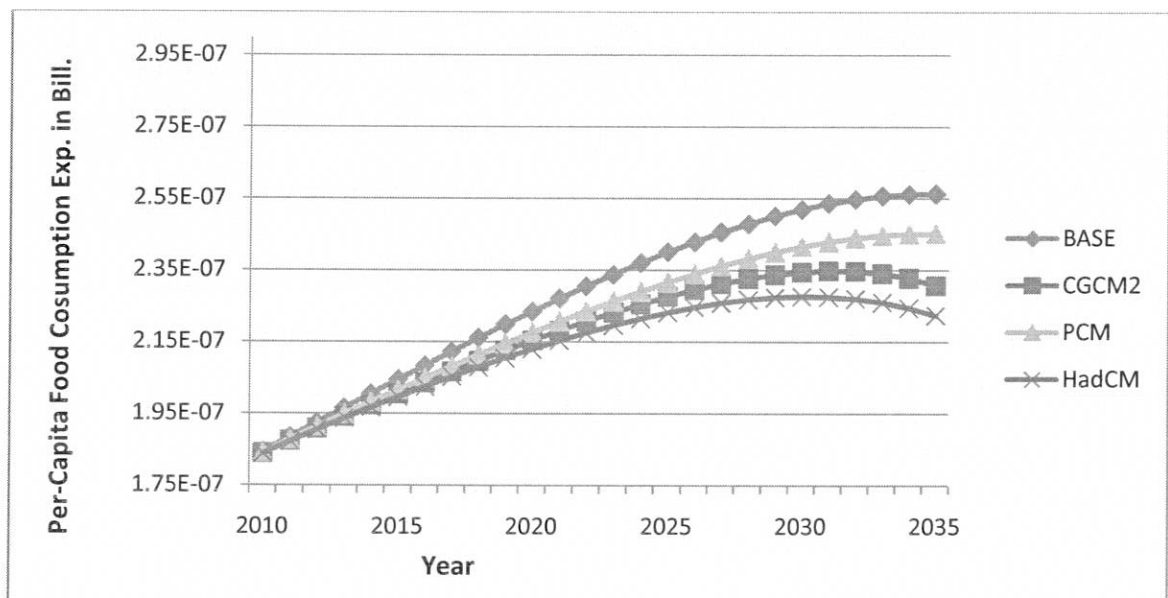


Figure 5: National Per-Capita food Consumption Expenditure in Bill.

Source: Simulation result with CGE Model.

#### 4.2.2.2. Urban and Rural Per Capita Food Consumption Expenditure

The rural and urban households are not expected equally to be impacted by climate change about their food consumption expenditure trend which depends on their food expenditure share from their income. In consisting with this expectation, the rural households' food expenditure shows almost a similar trend with the base line without climate change. Whereas, food consumption expenditure for urban household shows a greater variability in all climate change scenarios compared with the base. This is for the reason that rural household food consumption expenditure is relatively income inelastic than the urban (for example, expenditure elasticity of demand for teff is 1.08 for rural and 1.14 for urban; and expenditure elasticity of demand for animal product is 1.22 for rural where as 1.23 for urban ( Tafere, *et al.*, 2010)). The rural households are therefore insensitive to adjust their food consumption expenditure as their income level is changing. This argument entails that though the income of rural households is affected by a climate change, their consumption level will not vary by the extent that their income is changing; rather it continues to be constant.

This can be justified from the fact that the urban households are already attained their subsistence daily food requirement even with climate change as Table 8 below shows on. Thus urban households will be sensitive to adjust their consumption expenditure for food since they are enjoying extra consumption beyond subsistence. The other interesting result is per day food consumption expenditure for the rural is less than the income poverty line which is 1 dollar per day. This is true for all climate change scenario even for the base without climate change. Again, this fact makes the rural household to be less sensitive to income change in their food expenditure; because they do not even attained

their subsistence food requirement with the base scenario. The problem will be high with the fact that 80% of the Ethiopian population is rural inhabitant which leaves the country with high food poverty index. But, food poverty in the urban look to be less, as per capita food expenditure for all scenarios is above 1 dollar per day. But, a bad scenario would happen even for the urban if world food price shock had been considered in addition to climate change.

Table 8: Per Capita Food Consumption Expenditure per Person per Day

Scenarios	Urban	Rural
Base	1.60274	0.594521
CGCM2	1.476164	0.567123
PCM	1.523288	0.578082
HadCM3	1.452055	0.558904

Source: Self Computed from Simulation Result with CGE

This conveys an idea that urban households' food consumption declines because of climate change not only as their income is declining but also food supply declines as food production is negatively affected by climate change. From this analysis, it can be comprehended that to resist the climate change impact a stratified strategy is needed for both the rural and the urban area. In the rural the strategy should be intended to improve production through different adaptation schemes; and in the urban the strategy should focus in improving the market efficiency to raise the food supply and improving the income of the households. Hence, it holds necessary to discuss about the food market efficiency using the concept of market integration and the price transmission effect of climate change on different regions based on agro-ecological zoning.

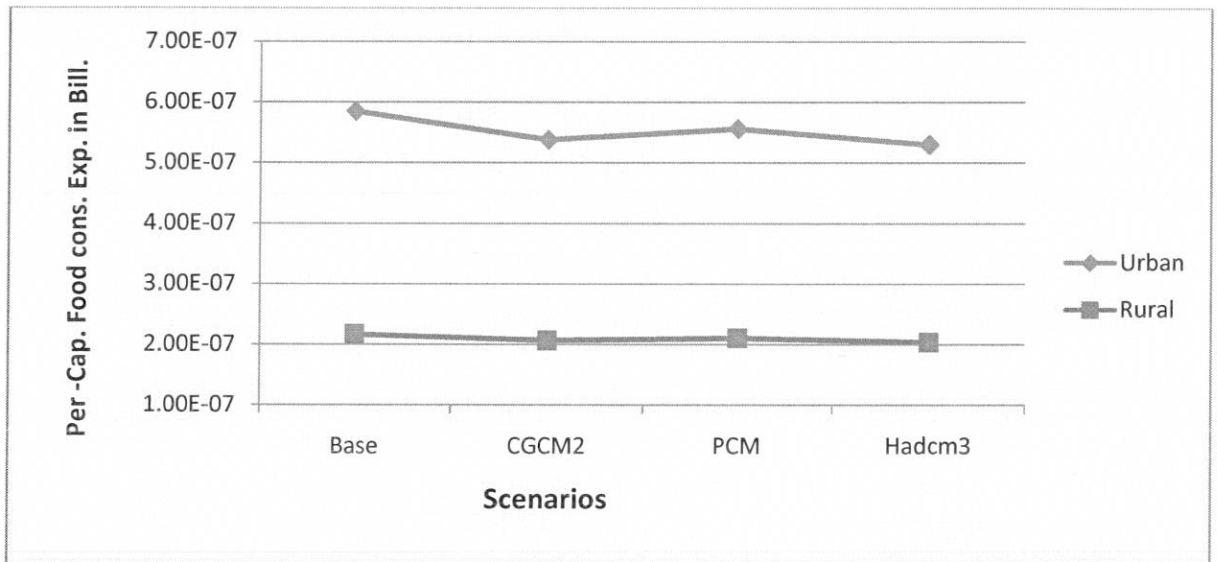


Figure 6: Mean per Capita food Consumption Expenditures for Urban and Rural Households in Bill.

Source: Simulation Result and Self Computed from CGE Model.

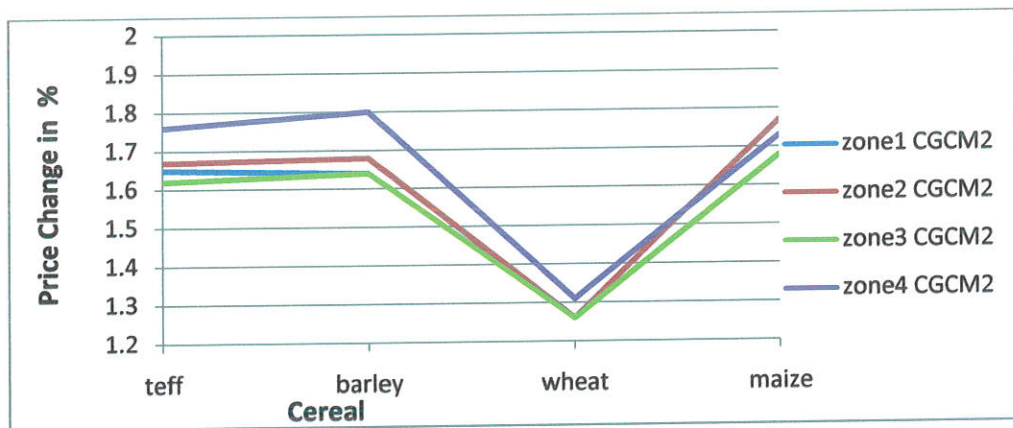
Indeed, the issue of market integration is a problem of market supply with regard to allocation across different market regions. To this fact the CGE model assumes a fixed market integration level across the four agro-ecological zones, all the climate scenarios are expected to result similar effects on price transmission in these regions. Hence only the effect of CGCM2 climate scenario is analyzed with regard to price change for major cereals in all agro-ecological zones<sup>11</sup>.

As Figure 7 displays, all regions show a slight variation in price change for teff, barely and maize. Teff and barely has increased by 1.65% for zone 1, by 1.7% for zone 2, by 1.6% for zone 3 and by 1.8% for zone 4. The divergence in percentage of price increment

<sup>11</sup> Zone 1 is highland cereal, Zone 2 is the moisture sufficient area, zone 3 is drought prone, and Zone 4 is the pastoralist area.

for teff and barely among regions shows a less integrated market. The regions are considerably integrated and shows similar price change trend for wheat. This is probably that wheat is supplied mainly from import and hence distributed across all regions by government enterprises. Thus, there will be a high tendency of similarity among regions in time of distribution and quantity of wheat supply based on the respective demand of the regions. It can be deducted that the food market for locally produced and supplied crops are less integrated than imported one. Regarding the integration level across regions, zone 1 and 3 are relatively integrated for barely, wheat and maize; whereas zone 4 is highly disintegrated for teff and barely as is signaled by a different price changes across the region. This implies that food availability and access problem is also challenged by allocation problem especially for domestically produced food items, as the markets are less integrated on.

Figure 7: Price Transmission Effect of CGCM2 scenario Across Agro-Ecological Zones



Source: Simulation result from CGE Model

### 4.3. Welfare Analysis

Apart from the market factor analysis, food security problem also implied from welfare change analysis. In CGE modeling, welfare change is analyzed using the equivalent variation of income for households (EV)<sup>12</sup>. The argument is if the welfare for a household changes, the food consumption level will change by a proportion of the change in income multiplied by the consumption propensity as food consumption appropriates the largest part of income expenditure which is a typical feature of poor economies like Ethiopia. Hence, a decline in general welfare will necessarily indicate a rise in food poverty and the converse holds true

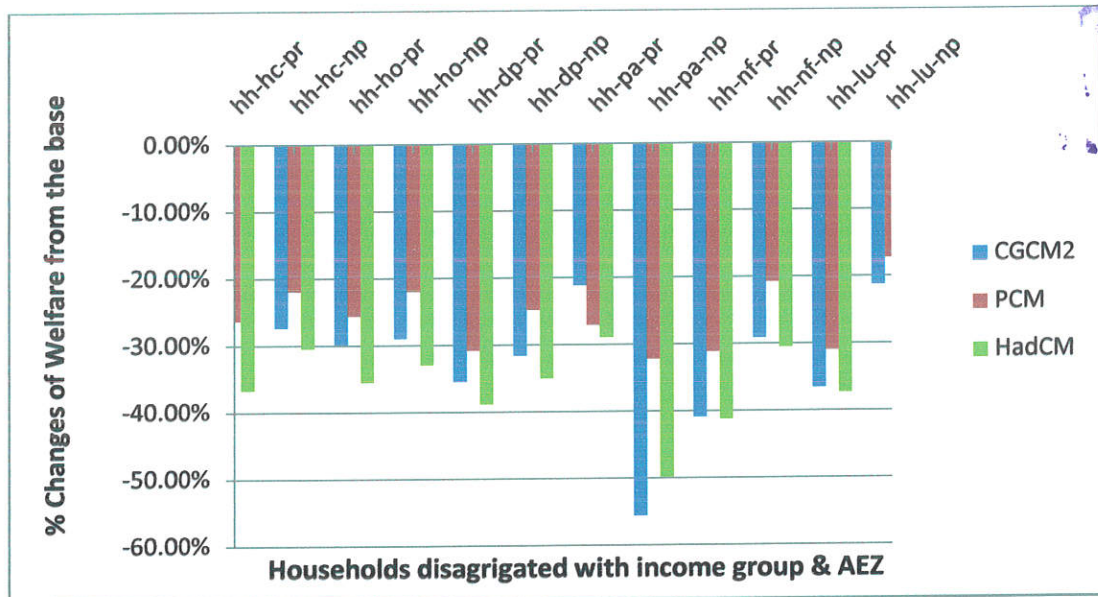


Figure 8: Percentage Changes of Household Welfares from Base

Source: Simulation Result from CGE Model

<sup>12</sup> Welfare change using the EV method is measured as a the change in income need to provide a household in order to enable the household, at the price level before the policy change or shock, to enjoy a satisfaction/utility level gained after the policy change or shock.

In the figure above hh-hc-pr is to mean high land cereal based area poor households, hh-ho-pr is highland enset based poor households; dp is for drought area, pa is for the pastoralist area, nf is the non farming rural, and lu is large urban area ; and np means non poor households.

Figure 8 shows all households suffered from welfare loss under climate change in all agro-ecological zoned. In specific however, the poor households are the most to suffer from welfare loss than the non poor households for all regions with the exception of the pastoralist area. In contrary, the large urban non poor households are the least to suffer from welfare loss. This implies that the impact of climate change on welfare of households and hence on food poverty depends on the size of income as the poor are the most to suffer from welfare loss under climate change in all regions; and it depends also on diversity of income source of households as the large urban non poor households are the least to suffer from welfare loss. In addition, this argument is justified by the fact that in the moisture sufficient high land cereal region, where there is dual farming, the non-poor households have lost their welfare below 40%; where as non-poor households in the pastoralist area with mono farming, only livestock production, have lost around 50% and above of their welfare with climate change. In addition, the large urban non-poor households with high and diversified income source have lost only 18% of their welfare with climate change. Across regions, the pastoralist non-poor<sup>13</sup> households' welfare is largely declining. This is consisting with the fact that urban households are showing less food poverty than the rural.

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<sup>13</sup> Poor imply all households falling in to the lowest two per capita expenditure quantiles.

## CHAPTER FIVE

### Conclusions and Policy Implications

#### 5.1. Conclusions

This thesis as an objective has tried to simulate the effect of climate change on food security status of Ethiopia with the IFPRI standard General equilibrium analysis model (CGE). In the simulation, it has tried to estimate all the market indicators of food security; and in the result food security is get to be worsened with climate change.

Regarding the impact of climate change on food availability, the simulation result portrays that on average per capita food production will decline by 20.9%, 18.01%, and 21.13% respectively based on the CGCM2, PCM, and HadCM3 climate scenarios compared with the base line. This will happen for the coming 25 years starting from 2010. The problem is significant as the yield growth elasticity for major cereals and livestock products is negative in CGCM2 and HadCM3 climate scenarios. This will pose a problem again with regard to food utilization.

As the result of the decline in domestic food production the country will become highly relying on imported food (both food aid and commercially imported food). This will make the country to be vulnerable to any world market price and supply shock. The decline in domestic food production also leads to push up the food price which reduces the purchasing power of households thus stacking their food access.

The per Capita GDP for all climate scenarios has shown an increasing trend. However, in the analysis of the per capita GDP ratio of the climate scenarios with the base, all

scenarios have exhibited an index less than one. This indicates that per capita income is decreasing with climate change. Households' purchasing power will therefore decline with climate change thus losing economic entitlement for food access.

As the result of a decline in per capita income, food consumption expenditure for the nation has shown a decline trend with climate change. This comprehends the fact that climate change intensifies food access and utilization problem because of a decline in per capita income and hence less food consumption expenditure. A high food consumption expenditure decline is resulted for the urban households than the rural. This is thought to be that rural households in Ethiopia are characterized with less income elasticity of food consumption expenditure. Though their income is declining under climate change, their consumption level remains relatively constant. The simulation has also shown that food poverty increases for rural household with climate change as their food consumption expenditure is already less than the subsistence food consumption expenditure per day even with the base scenario without climate change.

In terms of welfare change and hence a change in food poverty, the poor households are largely impacted with a decline in welfare level than the non-poor. The large urban non-poor are less impacted in their welfare. This point out that resistance to the impact of climate change depends on income level of households.

## **5.2. Policy Implication**

An implication for environmental policy change that could be drawn from the result is the fact that climate change is worsening the food insecurity problem in the country. As climate change is negatively impacting all market indicators of food security, it is needed

to forward adaptation strategies of climate change. From the finding the following recommendations are drawn;

- Since the impact of climate change on food production increases with time in scale, adaptation strategies should be increased and intensified in time length to reduce the effect of climate change on food production.
- As the country will become dependent on imported food as the result of climate change, it will be susceptible to any shock of world food production and price. It is recommended to make the agriculture sector climate change resilient by using different technology packages such as expanding irrigation farming, using fertilizers, improved farming technology and practices, and providing sufficient and timely information for farm households about climate forecasts.
- To resist the impact of the climate change, a stratified strategy is needed for both the rural and the urban area. In the rural the strategy should be intended to improve the agricultural production through different adaptation schemes and in the urban the strategy should focus in improving the market efficiency to raise the food supply and improving the income of the households. The market efficiency will be improved by establishing road infrastructure, communication and financial institutions. Again as climate change does not equally impact all agro-ecological zones, the climate change adaptation strategy should differ along the agro-ecological zones with a priority given to the arid and semi arid regions.
- In the last, it is recommended to diversify the economy's source of income which is less dependent on climate change.

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## Appendix

### *Appendix 1: Proof of Recardian Estimation Land Revenue Change over Time Gives TFP Growth*

Values of land revenue from the Recardian theory is given as a net profit of production by the following equation.

$$P_L L_t = P Q_t(K_t, E) - W K_t \quad \text{----- 11}$$

Where  $P_L$  is price of land per hectare,  $L_t$  is land size in hectare,  $P$  is price of the product,  $Q_t(K_t, E)$  is production function as physical inputs ( $K_t$ ) and environmental factors ( $E$ ), and  $W$  unit cost of physical inputs.

With perfect competitive product and resource market  $P$  and  $W$  are assumed to be the competitive constant prices.

Now differentiate both sides with respect to time.

$$P_L \frac{\partial L_t}{\partial t} = P \frac{\partial Q_t}{\partial t} - W \frac{\partial K_t}{\partial t} \quad \text{-----12}$$

Where,  $P_L \frac{\partial L_t}{\partial t}$  is net revenue change with time

$P \frac{\partial Q_t}{\partial t}$  is gross profit change, and

$W \frac{\partial K_t}{\partial t}$  is input cost change with time

Divide both sides with  $P Q_t$  and multiply the input cost change with  $\frac{K_t}{K_t}$ .

$$\frac{P_L \frac{\partial L_t}{\partial t}}{PQ_t} = \frac{\frac{\partial Q_t}{\partial t}}{Q_t} - \frac{WK_t}{PQ_t} \cdot \frac{\frac{\partial K_t}{\partial t}}{K_t} \quad \text{-----13}$$

Where,  $\frac{P_L \frac{\partial L_t}{\partial t}}{PQ_t}$  is net revenue change over time with respect to gross revenue

$\frac{\frac{\partial Q_t}{\partial t}}{Q_t}$  is output growth

$\frac{WK_t}{PQ_t}$  is input cost share from total income of the land, and

$\frac{\frac{\partial K_t}{\partial t}}{K_t}$  is input growth.

From Solow growth model, TFP (termed as Solow residual) is defined as the growth of output not explained by the growth in the physical inputs controlled in the model. TFP growth according to this definition is given by the difference in output growth and the product of input cost share and input growth. Hence the formula on the right side of equation 13 gives TFP growth or productivity elasticity (GTFP). Thus equation 13 can also be rewritten as;

$$\frac{P_L \frac{\partial L_t}{\partial t}}{PQ_t} = GTFP \quad \text{-----14}$$

That is net land revenue change over time with respect to gross revenue gives TFP growth under perfect product and resource market assumptions.

### 3. Activities and Commodity Lists of SAM for Ethiopia

Table 9: Activities and Lists of SAM for Ethiopia

Agriculture		Agro-processing		Other manufacturing		Other industry		Private services			
1	Teff	15	Tobacco	25	Meat	35	Textiles	49	Coal	55	Wholesale and retail trade
2	Barley	16	Coffee	26	Dairy	36	Clothing	50	Natural gas	56	Hotels and catering
3	Wheat	17	Flowers	27	Vegetable products	37	Leather products	51	Other mining	57	Transport
4	Maize	18	Other crops	28	Grain milling	38	Wood products	52	Electricity	58	Communications
5	Sorghum	19	Cattle	29	Milling services	39	Paper and publishing	53	Water	59	Financial services
6	Pulses	20	Milk	30	Sugar refining	40	Petroleum	54	Construction	60	Business services
7	Oilseeds	21	Poultry	31	Tea processing	41	Fertilizer			61	Real estate
8	Vegetables	22	Animal products	32	Other foods processing	42	Chemicals			62	Other private services
9	Fruits	23	Fisheries	33	Beverages	43	Non-metallic minerals				<b>Public services</b>
10	Enset	24	Forestry	34	Tobacco processing	44	Metals and products			63	Public administration
11	Cotton					45	Machinery			64	Education
12	Sugarcane					46	Vehicles and transport equipment			65	Health
13	Tea					47	Electronic equipment				
14	Chat					48	Other manufacturing				

Source: IFPRI Standard CGE Model for Ethiopia 2009.

#### 4. Simulation Results

Table 10: Per Capita Food Production in Billion

Year	BASE	CGCM2	PCM	HaDCM3
2009	3.79E-05	3.79E-05	3.79E-05	3.79E-05
2010	3.86E-05	3.79E-05	3.80E-05	3.79E-05
2011	3.92E-05	3.78E-05	3.81E-05	3.78E-05
2012	3.99E-05	3.78E-05	3.82E-05	3.78E-05
2013	4.06E-05	3.77E-05	3.82E-05	3.78E-05
2014	4.13E-05	3.77E-05	3.83E-05	3.77E-05
2015	4.20E-05	3.77E-05	3.84E-05	3.77E-05
2016	4.27E-05	3.77E-05	3.86E-05	3.77E-05
2017	4.35E-05	3.77E-05	3.87E-05	3.77E-05
2018	4.43E-05	3.77E-05	3.88E-05	3.78E-05
2019	4.52E-05	3.78E-05	3.90E-05	3.78E-05
2020	4.60E-05	3.78E-05	3.91E-05	3.79E-05
2021	4.69E-05	3.79E-05	3.93E-05	3.79E-05
2022	4.78E-05	3.80E-05	3.95E-05	3.81E-05
2023	4.88E-05	3.82E-05	3.98E-05	3.82E-05
2024	4.97E-05	3.83E-05	4.00E-05	3.83E-05
2025	5.08E-05	3.85E-05	4.03E-05	3.85E-05
2026	5.18E-05	3.88E-05	4.07E-05	3.87E-05
2027	5.29E-05	3.90E-05	4.10E-05	3.90E-05
2028	5.40E-05	3.94E-05	4.14E-05	3.93E-05
2029	5.51E-05	3.97E-05	4.18E-05	3.96E-05
2030	5.63E-05	4.01E-05	4.23E-05	3.99E-05
2031	5.75E-05	4.05E-05	4.27E-05	4.03E-05
2032	5.88E-05	4.09E-05	4.33E-05	4.06E-05
2033	6.01E-05	4.14E-05	4.38E-05	4.10E-05
2034	6.14E-05	4.19E-05	4.44E-05	4.15E-05
2035	6.27E-05	4.25E-05	4.50E-05	4.19E-05

Source: CGE Simulation

Table 11: Per Capita GDP in Billion

Year	BASE	CGCM2	PCM	HaDCM3
2009	5.66E-06	5.66E-06	5.66E-06	5.66E-06
2010	5.80E-06	5.75E-06	5.76E-06	5.75E-06
2011	5.93E-06	5.83E-06	5.85E-06	5.83E-06
2012	6.08E-06	5.93E-06	5.96E-06	5.92E-06
2013	6.23E-06	6.03E-06	6.07E-06	6.02E-06
2014	6.38E-06	6.13E-06	6.18E-06	6.12E-06
2015	6.54E-06	6.24E-06	6.30E-06	6.23E-06
2016	6.71E-06	6.36E-06	6.43E-06	6.35E-06
2017	6.89E-06	6.49E-06	6.57E-06	6.47E-06
2018	7.08E-06	6.63E-06	6.71E-06	6.61E-06
2019	7.27E-06	6.77E-06	6.87E-06	6.75E-06
2020	7.48E-06	6.93E-06	7.03E-06	6.90E-06
2021	7.69E-06	7.09E-06	7.21E-06	7.06E-06
2022	7.92E-06	7.27E-06	7.39E-06	7.23E-06
2023	8.15E-06	7.46E-06	7.59E-06	7.41E-06
2024	8.40E-06	7.66E-06	7.80E-06	7.61E-06
2025	8.66E-06	7.87E-06	8.02E-06	7.81E-06
2026	8.93E-06	8.10E-06	8.26E-06	8.03E-06
2027	9.22E-06	8.34E-06	8.51E-06	8.26E-06
2028	9.52E-06	8.60E-06	8.77E-06	8.51E-06
2029	9.83E-06	8.88E-06	9.05E-06	8.77E-06
2030	1.02E-05	9.16E-06	9.35E-06	9.04E-06
2031	1.05E-05	9.47E-06	9.66E-06	9.32E-06
2032	1.09E-05	9.79E-06	9.99E-06	9.62E-06
2033	1.12E-05	1.01E-05	1.03E-05	9.93E-06
2034	1.16E-05	1.05E-05	1.07E-05	1.03E-05
2035	1.20E-05	1.09E-05	1.11E-05	1.06E-05

Source: CGE simulation

Table 12: National Per capita food consumption Expenditure in Billion

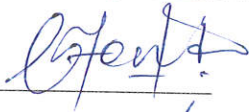
Year	BASE	CGCM2	PCM	HadCM
2009	3.07E-06	3.07E-06	3.07E-06	3.07E-06
2010	3.14E-06	3.13E-06	3.13E-06	3.13E-06
2011	3.21E-06	3.19E-06	3.19E-06	3.18E-06
2012	3.27E-06	3.25E-06	3.25E-06	3.24E-06
2013	3.34E-06	3.30E-06	3.31E-06	3.29E-06
2014	3.41E-06	3.36E-06	3.37E-06	3.34E-06
2015	3.48E-06	3.41E-06	3.43E-06	3.39E-06
2016	3.54E-06	3.46E-06	3.48E-06	3.44E-06
2017	3.61E-06	3.51E-06	3.54E-06	3.49E-06
2018	3.67E-06	3.56E-06	3.59E-06	3.54E-06
2019	3.74E-06	3.61E-06	3.65E-06	3.58E-06
2020	3.80E-06	3.66E-06	3.70E-06	3.62E-06
2021	3.86E-06	3.71E-06	3.75E-06	3.66E-06
2022	3.92E-06	3.75E-06	3.80E-06	3.70E-06
2023	3.98E-06	3.79E-06	3.85E-06	3.73E-06
2024	4.03E-06	3.83E-06	3.89E-06	3.77E-06
2025	4.08E-06	3.87E-06	3.94E-06	3.79E-06
2026	4.13E-06	3.90E-06	3.98E-06	3.82E-06
2027	4.18E-06	3.93E-06	4.02E-06	3.84E-06
2028	4.22E-06	3.96E-06	4.05E-06	3.86E-06
2029	4.25E-06	3.97E-06	4.08E-06	3.87E-06
2030	4.28E-06	3.99E-06	4.11E-06	3.87E-06
2031	4.31E-06	3.99E-06	4.13E-06	3.87E-06
2032	4.33E-06	3.99E-06	4.15E-06	3.86E-06
2033	4.35E-06	3.98E-06	4.16E-06	3.84E-06
2034	4.36E-06	3.96E-06	4.17E-06	3.82E-06
2035	4.36E-06	3.92E-06	4.17E-06	3.78E-06

Source: CGE Simulation

**DECLARATION**

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

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