CLIMATE CHANGE AND TECHNICAL OPTIMIZATION: THE APPLICATION OF AN INTEGRATED ASSESSMENT MODEL TO PAKISTAN

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ABSTRACT

Climate change is a big threat to Pakistan's agricultural sector, which is locked in low productivity, low technology, and hence operating below subsistence level. Crop production is expected to fall significantly following from frequent combinations of droughts and rainfall, as the technologically backward sector is unlikely to withstand the pressures of climate change. This begs the question on the optimum level of technical change required to address climate change effects on agricultural production. The principle objectives of the study are summarized herein: first, to identify the effects of climate change on the agriculture sector by decomposing them on crop specific levels; second, to determine the optimum level of technical change (TC) that can mitigate climate damages on agriculture; and third, to estimate the costs and benefits of the investments involved in implementing TC in agriculture and the overall economy. For projecting climate damages on 15 sub-sectors of agriculture, the study employs an integrated approach that combines the economic and ecological dimensions of the Pakistan economy. Using a dynamic Computable General Equilibrium (CGE) model, three scenarios were constructed in order to run simulations on climatic changes for agriculture. They include a baseline scenario with no climate change, a climate change scenario and a TC scenario to account for the mitigating potentials of TC. All economic activities are converted into a common unit, and then calibrated based on the economic data generated from the Social Accounting Matrix (SAM) of Pakistan. The climate parameters include climatic damage, carbon cycle, temperature and rainfall fluctuations, carbon emissions, vulnerability and carbon concentration, which are obtained from a Dynamic Integrated Model of Climate and Economy (DICE), and downscaled to fit in country specific outcomes, with a regional scope. The core findings of the study are as follows. First, climate change exerts a considerable negative impact on the agricultural sector in Pakistan. The magnitude of agricultural damages reflects the vulnerability of the sector. The damages on the sectoral level indicate significant distributional effects across agricultural crops, with expectations of largest economic losses for livestock, a key sub-sector for Pakistan. Second, the analysis reveals that TC moderates the damages incurred from climate changes and leads to steady increases in crop yields for all sub-sectors. More importantly, the study concedes that the costs of TC, though variations across sub-sectors of agriculture, are much lower than the damages imposed by climate change. The results, therefore suggest that an optimum level of TC adaptation is needed to produce net positive gains across sub-sectors. Third, TC has positive macroeconomic implications for the overall economy as it improves the gross domestic product (GDP) of Pakistan following from the rise in agricultural output. Further, based on the welfare criteria, TC is efficient as it improves production along with private consumption. Given the importance of TC for addressing the disproportionate effects of climate damages across the sub-sectors of agriculture, the study provides important implications for resource allocation to the underinvested sector of the economy. Specifically, it provides policy direction for prioritizing investments into sub-sectors of agriculture based on their exposure to climate damages.

ABSTRAK

Perubahan iklim merupakan satu ancaman besar kepada sektor pertanian di Pakistan, yang dikatakan mempunyai produktiviti yang rendah, teknologi yang rendah dan kesannya ia akan beroperasi di bawah tahap sara hidup. Pengeluaran tanaman dijangka menurun dengan ketara berikutan daripada kemarau dan hujan yang kerap berlaku, selain daripada penggunaan teknologi mundur yang tidak dapat menampung tekanan perubahan iklim. Ini telah menimbulkan persoalan iaitu apakah tahap optimum teknologi yang diperlukan untuk menangani kesan perubahan iklim ke atas pengeluaran pertanian. Objektif utama kajian diringkaskan di sini: Pertama, untuk mengenalpasti kesan-kesan perubahan iklim ke atas sektor pertanian dengan mengkelaskan sektor tersebut kepada beberapa tahap tanaman tertentu; Kedua, untuk menentukan tahap optimum perubahan teknikal (TC) yang boleh mengurangkan kerosakan iklim ke atas sektor pertanian; dan Ketiga, untuk menganggarkan kos dan faedah pelaburan yang terlibat jika TC dilaksanakan ke atas bidang pertanian dan ekonomi secara keseluruhan.Untuk meramalkan kerosakan iklim yang berlaku ke atas 15 sub-sektor pertanian, kajian ini menggunakan pendekatan bersepadu yang menggabungkan dimensi ekonomi dan ekologi untuk ekonomi di Pakistan. Dengan menggunakan model dinamik *Computable General Equilibrium* (CGE), tiga senario telah dikenalpasti untuk membuat simulasi ke atas perubahan iklim. Ia termasuk senario asas tanpa perubahan iklim, senario perubahan iklim dan senario TC yang mengambil kira potensi pengurangan TC. Semua aktiviti ekonomi telah ditukar kepada satu unit asas, dan kemudian ia ditentu-suaikan berdasarkan data ekonomi yang dijana daripada *Sosial Accounting Matrix* (SAM) di Pakistan. Parameter iklim adalah kerosakan iklim, kitaran karbon, suhu dan turun naik hujan, pelepasan karbon, pendedahan dan kepekatan karbon, yang telah diperolehi daripada *Dynamic Integrated Model of Climate and Economy* (DICE), dan saiznya telah dikecilkan untuk disuaikan dengan hasil sesebuah negara, dengan skop pendekatan yang digunakan adalah di peringkat daerah/kawasan.Penemuan utama kajian ini adalah seperti berikut. Pertama, perubahan iklim telah memberi kesan negatif yang besar kepada sektor pertanian di Pakistan. Magnitud kerosakan pertanian mencerminkan kelemahan yang berlaku di dalam sektor ini. Kerosakan pada peringkat sektor menunjukkan kesan pengagihan yang signifikan bagi setiap tanaman, dengan jangkaan kerugian ekonomi yang terbesar telah berlaku pada sub-sektor utama di Pakistan, iaitu ternakan. Kedua, analisis menunjukkan bahawa TC dapat mengawal kerosakan yang dialami akibat daripada perubahan iklim dan ia dapat meningkatkan hasil tanaman bagi semua sub-

sektor yang terlibat. Sebagai tambahan, kajian itu juga telah membuktikan bahawa walaupun kos TC berbeza mengikut sub-sektor pertanian, tetapi ia adalah jauh lebih rendah daripada kos ganti rugi yang akan ditanggung akibat perubahan iklim yang berlaku. Oleh itu, hasil kajian ini menunjukkan bahawa tahap penggunaan TC yang optimum adalah diperlukan untuk menghasilkan keuntungan bersih yang positif kepada semua sub-sektor. Ketiga, TC mempunyai implikasi makroekonomi yang positif kepada ekonomi secara keseluruhan kerana ia dapat meningkatkan Keluaran Dalam Negara Kasar (KDNK) bagi Pakistan berikutan daripada pertambahan pengeluaran di sektor pertanian. Selain itu, berdasarkan kriteria kebajikan, TC mempunyai tahap kecekapan kerana ia dapat meningkatkan jumlah pengeluaran dan penggunaan swasta secara serentak. Memandangkan kepentingan TC untuk menangani kesan-kesan yang tidak seimbang akibat daripada kerosakan iklim yang berlaku kepada seluruh sub-sektor pertanian, kajian ini memberi implikasi penting untuk pengagihan sumber kepada sektor ekonomi *underinvested.* Secara khususnya, kajian ini menyediakan hala tuju dasar yang mengutamakan pelaburan ke atas sub-sektor pertanian berdasarkan pendedahan kepada kerosakan iklim yang berlaku.

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LIST ABBREVIATIONS

IPCC : Intergovernmental Panel on Climate Change

DICE : Dynamic Integrated model of Climate and the Economy

CRU : Climatic Research Unit

RICE : Regional Integrated model of Climate and the Economy

GCISC : Global Change Impact Studies Centre’s

CCVI : Climate Change Vulnerability Index

CRED : Centre for Research on the Epidemiology of Disasters

GDP : Gross Domestic Product

CGE : Computable General Equilibrium

UN : United Nation

GHGs : Greenhouse Gases

FAR : First Assessment Report

TAR : Third Assessment Report

FAO : Food and Agricultural Organization

UNFCCC : United Nations Framework Convention on Climate Change

COP : Conference of the Parties

IIH : Induced Invention Hypothesis

TCR : Transient Climate Response

DAI : Dangerous Anthropogenic Interference

FDI : Foreign Direct Investment

ODA : Official Development Assistance

UNDP : United Nation Development Project

OECD : Organization for Economic Cooperation and Development

IAMs : Integrated Assessment Models

AEEI	:	Autonomous Energy-Efficiency Improvement
CES	:	Constant Elasticity of Substitution
CET	:	Constant Elasticity of Transformation
SCI	:	Social Cost of Carbon
ROW	:	Rest of the World
IO	:	Input-Output Table
SAM	:	Social Accounting Matrix
HIES	:	Household Expenditure Survey
CE	:	Cross Entropy
LDCs	:	Least Developed Countries
GAMS	:	General Algebraic Modelling System
IFPRI	:	International Food Policy Research Institute
GTAP	:	Global Trade Analysis Project
WDI	:	World Bank Indicators
TFP	:	Total Factor Productivity
R&D	:	Research and Development
ITC	:	Induced Technical Change
PPC	:	Production Possibility Curve
AEEI	:	Autonomous Energy-Efficiency Improvement
DCU	:	Domestic Currency Unit

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CHAPTER 1: INTRODUCTION

1.1 Overview

Climate change is one of the most pressing problems related to global environmental concerns (Walther et al., 2002), as the impacts of climate change can be felt far beyond the place that originates it (Schimel et al., 2001). According to the Intergovernmental Panel on Climate Change (IPCC), the average rate of global warming during the period 1990 to 2100 will be the most unprecedented than any seen in the last 10,000 years. This suggests a noticeable anthropogenic influence, particularly greenhouse gases (GHGs), on global climate (Pacala et al., 2001).

Climate change has the potential to disrupt economic activities, thereby impacting growth. Macro-level analyses show a strong correlation between economic output and temperature changes. It is found that a 4°C temperature increase results in a loss of 5 per cent of GDP (IPCC, 2007). The global integrated climate and economy models (DICE 2007, RICE 1999) further show that monetary damages increase with increases in temperature. Peters et al. (2012), acknowledge that global economic production is clustered near the estimated temperature optimum, as both rich and poor countries exhibit similar non-linear responses to temperature. However, the impacts of climate change can vary for different countries depending on the geographical location, and current climate conditions. Countries in the cool temperate regions are likely to benefit from global warming, while the countries in the hot and warm temperate regions are likely to suffer from increased temperature (Kurukulasuriya et al., 2006). For example, a rise in temperature in many parts of Asia, largely attributed to increasing frequency and intensity of droughts, caused severe economic losses (Lee et al., 2014; Onuchin et al., 2014).

Pakistan is located in the most disaster-prone region in the world. The temperature projections for South Asia for the twenty-first century suggest a significant acceleration of warming over that observed in the twentieth century (IPCC, 2007). Pakistan experienced some of the hottest and driest conditions in the South Asia region. The hottest year recorded in the history of Pakistan was 1998, due to the heat waves of the East-Equatorial Pacific water (Thenkabail & Gamage, 2004) . According to the Climatic Research Unit (CRU), though past temperature trends for the country do not display a consistent pattern, it shows an overall increase of 0.6^{o}C over the past century (Ul Islam et al., 2009). Based on the Global Change Impact Studies Centre's (GCISC) projections, the temperature is expected to rise by about 2^{o}C in northern Pakistan, 1.5^{o}C in central parts of the country and 1^{o} C in coastal areas by 2020s. With the change in temperature, other climate parameters are also affected, such as the annual rainfall. Only in 2005, the rainfall kept the temperature in normal range.

It is also important to recognize that effects of climate change are not homogeneous among different sectors of a country. The agriculture sector is considered the most vulnerable to climate-induced damages because its production is directly dependent on the weather conditions (Easterling & Apps, 2005). It is also an important sector, particularly for developing nations, as it is linked to food security, poverty reduction, and economic development. Due to continued climate variability in addition to extreme events, the agriculture sector will be forced to cope with these changes (Morton, 2007), which will then affect production, costs of production and market price of agricultural produce.

The growing risks of climate change damages/hazards demand appropriate action from policymakers to minimize the negative impacts of the climatic conditions. Two strategies are popularly known to cope with the negative impacts of climate change, mitigation, and adaptation. Mitigation is an act to reduce the activities that cause faster climate changes, while adaptation refers to the capability to adapt to changed conditions.

Progress on reducing emissions through mitigating policy generally do not provide the intended results, as it has no direct impact on the economic growth of a country. On the other hand, existing knowledge regarding adaptive capability and adaptation options are inadequate. There is still a lack of reliable projections on adaptation and its associated costs in terms of monetary value (Smith & Lenhart, 1996).

Since technical change is important to address long-term environmental problems such as climate change, this begs the question on the optimum level of technical change required to address climate change effects on agricultural production. Therefore, addressing climate change necessitates broad-range technical changes that can facilitate efficient reallocation of resources for conducting economic activities. Technical change policy, therefore, offers potentials to overcome barriers to climate change mitigation. In this context, technical change has emerged as an appealing solution to address the impacts of climate change in the agricultural sector in particular and the overall economy.

The costs of climate change measures further and cannot be optimally determined on a global basis, as the impact varies between countries (Hunt & Watkiss, 2011). It follows then that assessing the costs and benefits of any policy response to climate change at the country-specific level is important, as the effectiveness of the policy needs validation for further implementation.

1.2 Problem Statement

According to the German Watch index, Pakistan is among the top 10 most vulnerable countries and one of the top three disaster-prone countries globally (Burck et al., 2014). The Climate Change Vulnerability Index[1] (CCVI) ranks Pakistan in the high-risk zone, as it moved from the 29th most vulnerable country for 2009-2010 to the 16th position in 2010-11. The rise in the ranking came with the higher changes in temperature, rainfall, and other climate parameters. According to the Centre for Research on the Epidemiology of Disasters (CRED) (2012), 6.3 per cent of the 72.7 million people in Asia that were hit by climate-induced disasters (floods, typhoons, droughts, and food shortages) in 2012 were from Pakistan. The last two decades witnessed escalating extreme events in Pakistan. Large-scale flooding in 1992, 1997, 2003, 2006, and 2012-14, resulted in monetary damages of $10 billion in 2010-2011. However, the worst droughts occurred during 1999-2002 and 2014/15.

Amidst the vulnerability of its economy to extreme climatic changes, Pakistan is an agrarian economy that operates on a subsistence level. The agriculture sector accounts for 45 per cent of the labour force, 21 per cent of GDP, and 70 per cent of total export earnings. The importance of agriculture can be seen in three ways: first, it provides food and fiber to consumers and the domestic industry; second, it is a source of foreign exchange earnings; and third, it provides a market for industrial goods (GoP, 2014). Despite the importance of the agricultural sector in Pakistan, the production of all its crops has been falling way behind the global average, and the mode of production has yet to be commercialized. The volatile weather conditions add to the productivity problems in this sector, with major crops showing persistent yield gaps (Arifullah et al., 2009). The performance of other important sub-sectors like livestock also remained weak (Pakistan Bureau of Statistics, 2013/14). With low levels of technology and capital stock, the

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[1] The CCVI was developed on the basis of 42 social, economic, and environmental factors of 170 countries. These factors comprised the form and frequency of natural disasters, sea level rise, along with some other Social, environmental and economic indicators, for example, population, natural resources, economic status and vulnerable sector (agricultural sector specially) dependency.

agricultural sector is clearly not able to withstand additional pressures from climate change, as shown in Table 1-1.

Table 1-1 Physical Impacts of Climate Change on Agriculture

Climate Change	Possible Impacts
Increasing temperature	1. Decreased crop yields due to heat stress and increased rate of transpiration 2. Increased livestock deaths due to heat stress 3. Increased outbreak of insect pests and diseases
Changes in rainfall	1. Increased frequency of drought and floods causing damages to crops 2. Changes in crop growing season 3. Increased soil erosion resulting from more intense rainfall and floods
Sea-level rise	1. Loss of arable lands 2. Salinization of irrigation water.

Source: Compiled from the literature.

Climate change involves more than having an adverse effect on the productivity of crops and fodder for livestock, affecting supplies and pushing up market prices (Kurukulasuriya et al., 2006). It will also adversely affect the balance of payments and economic growth. Taking into account of the seriousness of this matter, the Pakistan National Policy on Climate Change was developed in 2012. The main goal of the policy is "*To ensure that climate change is mainstreamed in the economically and socially vulnerable sectors of the economy and to steer Pakistan towards climate resilient development*". The main policy objectives are as follows:

1. To pursue sustained economic growth by appropriately addressing the challenges of climate change.
2. To ensure water security, food security, and energy security of the country in the face of the challenges posed by climate change.
3. To strengthen decision making and coordination mechanisms on climate change.
4. To foster the development of appropriate economic incentives to encourage public and private sector investment in adaptation measures.
5. To enhance the awareness, skill, and institutional capacity of relevant stakeholders.

The national policy is based on adaptation and mitigation principles of sustainable development, coordinated implementation, effective participation and common but differentiated responsibilities. However, the implementation of such a policy is a big challenge due to the lack of proper scientific research regarding costs and benefits of such policies. Furthermore, this policy focuses on adaptation, while ignoring the pre-conditions of technology for adaptation. This study, therefore, seeks to provide the optimal technical change required to address climate change damages.

1.3 Research Questions

The study seeks to answer the following questions:

1. To what extent is agricultural production affected by climate change?
2. Are climate change effects homogenous across major crops of the agricultural sector?
3. Is technical change important for addressing climate change effects on agricultural production?
4. What is the optimum level of additional technological change required to increase agricultural production?

5. How does optimum technical change benefit the agricultural sector in particular, and the economy as a whole?
6. What will be the estimated costs of technical change for agriculture and for the overall economy?

1.4 Objectives of the Study

The main objective of this study is to analyze the costs of the technical change needed to counter the negative impacts of climate change on the agricultural sector of Pakistan. The specific objectives are delineated below:

1. To estimate the aggregate impact of climate change on agricultural production and across agricultural sub-sectors;
2. To investigate the optimum level of additional the Hicks's technical change required to address climate change effects and increase agricultural production; and
3. To estimate the benefits and costs of optimal Hicks's technical change for the agricultural sector and for the overall economy.

1.5 Significance of the Study

The contributions of this study are to estimate the macroeconomic effects of technical change policies on the Pakistan economy. Specifically, this study offers the following:

1. Providing theoretical explanations on the role of technical change as a mitigating or adapting factor to climate change effects for the economy;
2. Contributing to the empirical evidence for Pakistan on the distributional of impacts of the costs of technical change for different crops of agricultural and livestock sector;
3. Provide policy input on the overall impacts of technical change as a measure to address climate change;

4. Informs the policy debate setting for up a long-term national technical change policy framework for Pakistan, which could be an addendum to the existing national policy on climate change.

1.6 Organization of the Study

Chapter 1 sets the background of the study, details the problem statement, research questions, and research objectives. It also discusses briefly the significance and limitations of the study. Chapter 2 reviews the theoretical literature on climate change and agricultural production. It also draws upon the theoretical explanation for technical change as a mitigating and adapting factor for addressing climate change.

Chapter 3 profiles the climate change perspective of Pakistan as well as the anticipated future climate catastrophes and trends in agricultural production. It describes the climatic changes in Pakistan and the role and prominence of the agriculture sector, to set the background of the study. It highlights the need of mindful measures to address looming dangers of climate change in the predominantly agricultural society of Pakistan. Chapter 4 discusses the conceptual framework and empirical strategy. It elabourates the basic features of the model used in the study, and how computable general equilibrium model (CGE) and climate parameter are integrated to form an integrated assessment model (IAM). It also describes the data dimensions, construction, and balancing mechanism of the Social Accounting Matrix (SAM).

Chapter 5 presents and discusses the findings related to the impact of climate change on the agricultural and livestock sectors. Similarly, Chapter 6 shows the outcomes of technical change actions under climate change conditions. Subsequently, Chapter 7 compares the findings under different scenarios to identify impacts of technical change.

Chapter 8 concludes the study with a summary of the main findings and some policy recommendations.

CHAPTER 2: LITERATURE REVIEW

2.1 Introduction

This chapter reviews the literature relating to the impact of climate change on agriculture production. In light of impacts of climate change, the literature review is divided into two main components. The first component refers to the theoretical elucidation of climate change impacts on agriculture production, while the second elabourates on the empirical findings.

The first component starts with the definition of climate change and it goes on to elabourate on its global and regional impacts. Further, it sheds some light on climate change impacts in the South Asian region. It unpacks the physical and economic implications of climate change. Furthermore, it provides a brief description of the climate change response actions and their limitations, particularly in the case of developing countries. The section then highlights the role of technical change in mediating climate damages. Afterwards, the methodologies used to gauge climate damages in agriculture are discussed with their pros and cons. The last part of the first section provides a theoretical exposition of the climate change effects on agricultural production. In this section, climate change theories are connected with agricultural production theories to provide a theoretical foundation for the study.

The second component is composed of empirical findings related to climate change and agriculture production. Empirical studies have ascertained a significant and direct impact of climate change on agricultural production. Concisely, among other factors, climate change effects are tied up with agricultural production in this section. The first part of this section explains the global effects of various climate parameters on agricultural production. It then elabourates on the economic losses to global agricultural production as a result of changing climate conditions. The second part describes the effects of climate change on South Asian agricultural production. The last part of this section unpacks the empirical findings using IAM's. The last part of the chapter summarizes the key points of the review.

2.2 Climate Change Exposition: Definitions and Impacts

The climate is a natural resources; indispensable for well-being, health, and prosperity of humanity. Simply put, climate can be defined as average weather, where climate change is the noticeable change in the Earth's regional or global climate system over a period of time. However, in view of policy makers 'climate change' is a contemporary rise in average temperature of earth known as Global warming (Chandrappa et al., 2011) . The inception of the industrial revolution in the middle of 1760s and1800s catalyzed the use of coal, which accelerated the phenomena of global warming and climate change (Gerlagh, 2008; Satterthwaite, 2009).

Variation of climate from year to year has been attributed to natural processes. Researchers like Sprugel (1991) devised the concept that pragmatic changes in natural processes and climate are likely to be dependent on natural variability. Crowley (2000) supported the same idea, but highlights that the feedback of natural process can be positive or negative likewise, the climate response can also be positive or negative respectively (Grudd et al., 2002; Hulme et al., 1999). In fact, variations in climate are not bound to any time scale. Variations can be years to decades, from millennia to millions, and even billions of years, depending upon a number of factors, some external to the climate system, while others are internal (Quante, 2010).

With the passage of time, anthropogenic influence of climate variability emerges as a troublesome entity in the climate systems (Salinger, 2005). Many researchers like Santer et al. (1996) interpreted human activities as a catalyst to climate change.

Eventually, IPCC (2007) proclaimed with a high confidence, that anthropogenic activities are warming the climate. This generates the consensus between a global scientific community that, by and large, human activities are responsible for the contemporary acceleration in climate change (Rosenzweig et al., 2008; Sillmann & Roeckner, 2008).

Anthropogenic activities afflict earth climate, by changing the greenhouse gas concentration in the atmosphere. However, the size of variation can vary from micro to macro, regional to national, and national to the global level. Many economists like Pall et al. (2011) believe that anthropogenic era of climate change began with the advent of the industrial revolution. Meanwhile, a heap of studies (Allen et al., 2000; Giorgi et al., 2001; Knutson et al., 2010; Stott, 2003) concluded that anthropogenic activities were dominant in causing recent climate change rather than natural forces. Figure 2-1 summarizes the natural and anthropogenic factors that contribute to climate change.

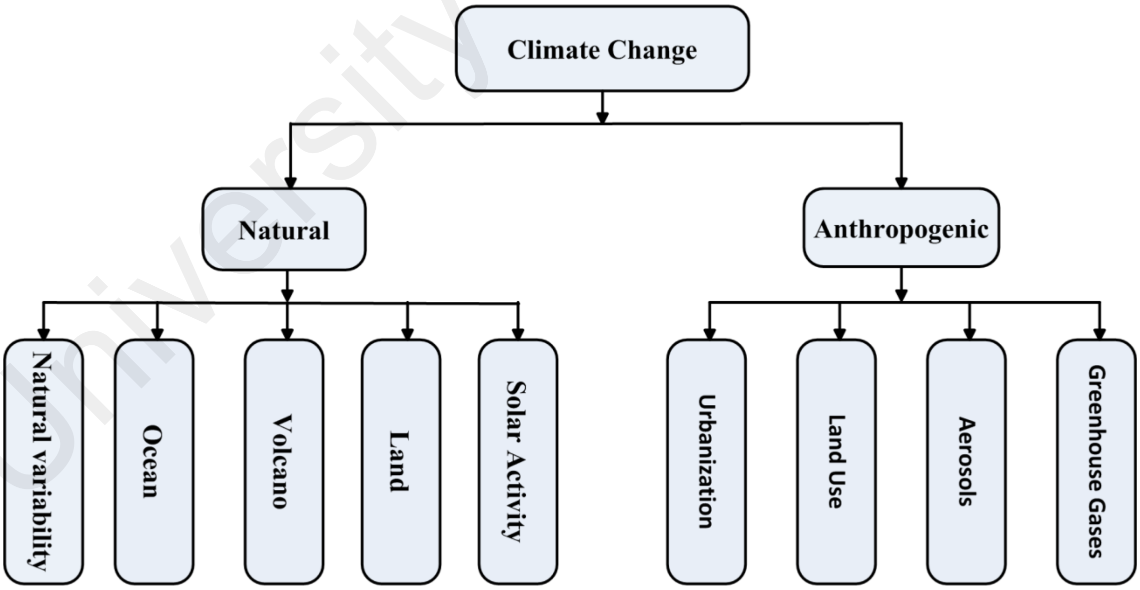

Figure 2-1 Factors Causing Climate Change

Source: Compiled from the literature.

Many scholars presented climate change as a gruesome environmental externality due to its uncertain nature. For example, Benjamin (2012) described that effects of climate change are pervasive because the sources of greenhouse gas emissions are more diffuse, granted that every household, company, and farm emit greenhouse gas. Even though anthropogenic changes in global climate are evident, scientific debate continues on the relative size and magnitude of anthropogenic causes of climate change.

Hegerl and Zwiers (2011) illustrated that neither natural variability nor anthropogenic activities are exclusively responsible for the witness changes in climate and natural systems. This concept is further explored by Rosenzweig et al. (2008) and he coined the term "Attribution" for assessing the impacts of climate change. Therefore, the changes in climate systems were further analyzed, owing to the distinguished dimensions of natural and anthropogenic cause. Within the setting of impacts, attribution is mainly the magnitude of the contribution of the natural or anthropogenic cause of climate change. Additionally, combining both types of attribution is termed as 'Joint Attribution' of natural and anthropogenic effects on the climate system. Scholastic work done by McCarthy (2001) found that climate is changing naturally, while human activities are exacerbating the change. There is much academic work that will endorse this argument (Hughes, 2004; Parmesan & Yohe, 2003; Root et al., 2003).

2.2.1 Global Impacts of Climate Change

Climate change is a problem that is ‘‘global common". It is long-term (up to several centuries), and involves complex interactions between several factors including climatic, environmental, economic, political, institutional, social, and technological processes. Titus (1992) illustrates that evidence of global climate change is compelling. Similarly, Fankhauser (1994) in his study expatiated on the nature of climate change; to him, it is the mother of all externalities: larger, more complex, and more uncertain than any other problem. In the same way, Darwin and Kennedy (2000) explained that it is a growing crisis with economic, health, food production, security, and other dimensions.

More specifically, Reilly et al. (2003) illustrate that climate change associated with increasing levels of carbon dioxide is likely to affect developed and developing countries differently, with major vulnerabilities occurring in low-latitude regions. McIntosh et al. (2000) further shed light on the distinctive nature of climate change and argued that climate change possesses a blend of opportunities and misfortunes. Similarly, Mortimore and Adams (2001) briefly explain its diverse impacts on societies and describe that some societies will reap from the opportunities while already marginalized societies will be exposed to amplified vulnerabilities.

The United Nation (UN) sponsored IPCC, which summarizes and evaluates scientific studies on climate change comprehensively and credibly, asserts that atmospheric concentrations of carbon dioxide, methane, and nitrous oxide have grown by about 31 per cent, 51 per cent, and 17 per cent, respectively. Since the industrial revolution began, significant quantities of greenhouse gases (GHGs) have been added to the atmosphere, which increases warming potential. Various researchers like (Allen et al., 2009; Cox et al., 2000; Vitousek, 1994) indicated that first decade of the 21st century was the warmest[2] since the beginning of temperature record keeping (1850). This implies that atmospheric and ocean temperature is rising with apparently dangerous looking effects. Subsequently, Kharin et al. (2005) advocate that increases in temperature would lead to an increase in the frequency of extreme events. Later Tebaldi et al. (2006) acknowledge the fact that high extremes may also be exacerbated by changes in other aspects of climate,

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[2] On average it was 0.2ºC warmer than preceding warmest decade of the 20th century (1991-2000) and 0.4°C warmer than the recoded temperature from 1961 to 1990.

including circulation. In a recent study Min et al. (2011) argues that increase in anthropogenic greenhouse gases to date has probably doubled the likelihood of heat wave incidents. Likewise, researchers also argue that the intensity of extreme events, altered rainfall and drought patterns, and temperature extremes show an increase in the past several decades.

Besides extreme events and temperature increase researcher also claimed that climate change, particularly by temperature increases affecting global natural systems. Trenberth (2011) affirm that global warming pattern will increase the glacier melting and catalyze sea level rise. Further, Walther et al. (2002) emphasize that warming of oceans and ice melting will bring a historical rise in sea level. The impact of sea-level rise will have far-reaching consequences for global coastal areas since the coastal areas are under a wide range of human and natural stress of recreation and development. The catastrophic sea level rise will cause the displacement of hundreds of people and generate social chaos (Rahmstorf, 2010; Raper & Braithwaite, 2006).

Nicholls and Cazenave (2010) proposed that rapid rise in sea levels not only increases the risk of catastrophic flooding but also contaminating coastal fresh water. On the contrary, intense changes in precipitation will facilitate flooding and droughts. Although arid areas are prone to drought, wet and humid regions also witness droughts due to frequent shifting of weather patterns. McMichael et al. (2007) proclaimed that such shifting weather patterns threaten food production across the globe. The uncertainty and risk of warming and drying make entire ecosystems prone to reach thresholds of dramatic climate change.

Besides that, researchers have claimed that alarming evidence exists that there are important tipping points, leading to irreversible changes in global climate system, and that these tipping points have already been reached or passed. The cumulative effects of climate feedback systems that are shaping across earth demonstrate unique behavior that can’t be anticipated. For example, Weitzman (2012) pronounced that the damages in last decades from severe weather events escalated from the combined damages of the 1980s and 1990s. Taken together, the synthesis of current knowledge of climate processes and observed and projected climate changes suggests discernible impacts of global climate change on the entire natural system. Therefore, global climate change of late has taken the center stage of academic research. Hence, a raging debate on the theme was published apart from the popular writings and research articles.

2.2.2 Regional Impacts of Climate Change

This section serves as an introduction to the regional dimensions of climate change. It provides context for an assessment of regional aspects of climate change in different parts of the world. Although the climate system is global, climate change has its manifestation in atmospheric processes, ocean circulation, bioclimatic zones, daily weather, and longer-term climate trends that are regional in their occurrence, character, and implications. Thus knowing the importance of the regional context evolution in the treatment of regional aspects of climate change can be found in IPCC reports. For example, the First Assessment Report (FAR) was followed by more systematic coverage of regional issues on request of governments, leading to the special report on the regional impacts of climate change in 1998.

Devkota et al. (2013) demonstrate that most of the vital sector for sustainable development is considered climate sensitive; however, food and fiber production are extremely vulnerable to climate change. According to Hayhoe (2010), regional variation of climate effects on food production are particularly important because it depends on the distribution of solar heating, ocean and land surface temperature response, and interaction between physical characteristics of the regions. A number of scholastic works for example

Patz et al. (2005) and Hansen et al. (2012) asserted that some of the regions will experience adverse impacts of climate change that are irreversible, while some will be likely beneficial.

Focusing on the regional dimensions of climate change, Garcia et al. (2014) advocate that changes in climate exert additional stress on those systems already affected by increasing resource demands, unsustainable management practices, and pollution. Moreover, the additional stresses will interact in different ways across regions. In doing so, it will reduce the ability of the environmental system to provide vital goods and services for economic and social development on a sustainable basis.

Acknowledging the fundamental importance of ecosystems for environmental function and sustainability, Boyd and Doney (2002) argued that it provide many goods and services critical to individuals and societies. In addition, natural ecosystems have cultural, religious, aesthetic and intrinsic existence values. Richardson et al. (2013) revealed that changes in climate have the potential to affect the geographic location of ecological systems, the mix of species that they contain, and their ability to provide the wide range of benefits on which societies rely for their continued existence.

Thornton et al. (2010) discovered that Africa is arguably the most affected region of widespread and potentially devastating impacts of climate change. According to Buhaug (2010), the vulnerability of the African region is exacerbated particularly because of widespread poverty, recurrent droughts, inequitable land distribution, and overdependence on rain-fed agriculture. Although some coping strategies are available, theoretically, in practice, infrastructural and economic response capacity to generate timely response actions is well beyond the economic means of various countries (Agrawal, 2010; Roudier et al., 2011).

Similarly, the projected climate impacts on Antarctic Peninsula and the Arctic are very devastating (Thompson et al., 2011). The affected number of people are few but climate change can disturb the traditional life style of native communities. The direct effects can be seen by the ecosystem shifts, sea and river-ice loss, and permafrost thaw. Indirect effects include climate system feedbacks such as further releases of greenhouse gases, changes in ocean circulation drivers, and increased temperature and higher precipitation with the loss of ice, which could affect climate and sea level globally (Meredith & King, 2005).

The arid region of the world is another victim of climate change. Conferring water shortage Hanjra and Qureshi (2010) claim that most of the arid region will permanently face water shortage. Similarly, highlighting the importance of water for food and fiber production Iglesias et al. (2007) asserted that water shortage in arid regions generate serious repercussions for food production in coming decades. Moreover, land degradation problems emerged with extreme climate events, limited present agricultural productivity, and this threatens the future food security of some countries. Hence, currently food and fiber production concentrated on more intensively managed land to reduce the detrimental impacts of extreme climatic events. Countries of arid region are undergoing major economic changes, particularly in agricultural systems and management (Cooper et al., 2008; Gornall et al., 2010; o'Brien et al., 2004).

Olesen and Bindi (2002) claim that despite the vibrant capabilities of Europe to adopt climate change, significant negative impacts can be anticipated. Major effects are likely to concentrate in the changes of extreme events and precipitation, causing more droughts in some areas and more river floods elsewhere. In view of these changes (Reidsma et al., 2010), major effects can be felt primarily in agriculture and other water-dependent activities. For the agricultural sector, reduction of frost risk due to a warmer climate will expand potential yields of winter crops especially in central and southern Europe. Similarly, higher spring temperature would extend most of the summer crop yield, though Western Europe may experience decreases in potential yield. Moreover, projected rate of climate change will hamper ecosystems in the entire European region (Lindner et al., 2010; Seidl et al., 2014).

Similarly, a researcher like Harrington et al. (2001) and Wiedner et al. (2007) argued that temperature increase will bring some benefits in temperate regions of the world like New Zealand. The higher temperature increases crop productivity and expands the growing season period. Admitting the water shortage conditions in Australia, Murphy and Timbal (2008) contended that water shortage will exacerbate climate damages. They further explain that due to moderate vulnerability of other sectors, particularly ecosystems, hydrology, coastal zones, human settlements and human health net effect remains positive under climate change conditions.

Among all the world regions Asia is the most populous. Over the entire region of Asia, temperature is projected to increase by3°C in the decade of the 2050s and about 5°C in the decade of the 2080s according to the Third Assessment Report (TAR) of the IPCC (Lal, 2001). The reported extreme weather events in Asia provides evidence of variation of climate throughout the 20th century (Christensen et al., 2007). Likewise, Japan Meteorological Agency asserted that annual increase in the winter precipitation would be highest in the entire Asian continent, which has serious repercussions for the annual runoff of major rivers. Angling in a different way Kurihara et al. (2005) stated that variation in monsoon makes tropical Asia more prone to floods. Expressing the rainfall variation Ichikawa (2004) declared that arid and semi-arid regions will face severe water stress and expansion of deserts due to decline in summer precipitation.

Besides rainfall variation researchers like Srinivasan & Hunt (2011) professed that climate change will disturb ecological balance in Asia. It will affect agriculture, human health, biodiversity, water resources, and sea level. Considering the burgeoning population of Asia, Challinor et al. (2014) highlight the danger of malnutrition among poor and marginalized communities due to a potential reduction of cereal production in Asia. Similarly, the projected future sea-level rise could inundate low-lying areas, exacerbate flooding and increase the salinity of irrigation water (Elliott et al., 2014; Powlson et al., 2014).

In summary, evidence suggests the systems controlling the world's climate can lurch from one state to another. Despite the fact that certain predictions cannot be made with high confidence, the changes in certain threshold events may become more probable. Surprises should be anticipated, which can increase our vulnerability to significant impacts by posing great challenges to our ability (Preston et al., 2008). The scientific literature currently available on the projected global climate change has been shifting from gradual to rapid or abrupt change. However, the future impacts of climate change would be different across regions and sectors. The broad ranging impacts of changing climate will be seized in agriculture, biodiversity, water resources, heat and cold related mortality, coastal zones, and floods. All in all, a significant linkage exists between all the vulnerable sectors and climate catastrophes. The economic damages consideration of these linkages is helping to moderate policy debate (Stern, 2007) .

2.3 South Asian Perspective of Climate Change

South Asia consists of Afghanistan, Bangladesh, Bhutan, India, Maldives, Nepal, Pakistan and Sri Lanka and is home to over one-fifth of the world's population. Moreover, most of the studies focus on India, Pakistan, and Bangladesh, because a significant portion of their national economies is dependent on agriculture (Schlenker & Lobell, 2010).

Among the studies conducted on climate change and agricultural production, most of the studies found that climate issues of South Asia by and large similar to Sub-Saharan Africa (World Bank 2009). However, according to the United Nations Environment Programme (UNEP) South Asia is the most disaster-prone region in the world.

To begin with, farming techniques in this region are relatively primitive, the majority of the region is arid, and the smallholder systems that dominate the agricultural landscape have very limited capacity to adapt (Müller et al., 2011). In measuring food security and population growth Easterling and Apps (2005) argue that higher population growth rate in the South Asian region continuously pushes the poverty rate up leading to the massive food insecurity threats. Further, Turner and Annamalai (2012) highlight that climate change is exacerbating food security threats by decreasing the productivity of agricultural, forestry, and fishery systems in South Asian countries.

Much of the work on climate change effects on developing countries' economies focus on the agricultural sector. Hence, it has emerged as a pressing issue late, Mirza (2011) expounded past and present climate trends and variability in South Asia, and found that temperature increase in South Asia ranged between 1–3°C per century, coupled with variability in rainfall during the past few decades. Further augmenting their findings Kelkar and Bhadwal (2007) illustrated that temperature increase in South Asia ranged between 1–3°C per century, while a decrease along coastal belts and arid plains of Pakistan and increase in Bangladesh are more pronounced.

Likewise, Devkota et al. (2013) conducted an empirical study to find the link between climate change and extreme events in South Asia. They took floods as an indicator of extreme events. Their study concluded that South Asia shows an increasing tendency in the intensity and frequency of extreme events in the past decade. Concentrating on the frequency of climate extremes and climate change, Turner &

Annamalai (2012) administrated a study focusing on heat waves and rainfall. They found that longer heat waves in many South Asian countries have been observed along with more intense rainfall events. The higher frequency and intensity of rainfall has serious repercussions in the form of severe floods, landslides, and debris/mud flows. However, it is interesting to note that Kelkar and Bhadwal (2007) found that total amount of annual precipitation has decreased with the decrease in the number of rainy days. This shows that rainfall has decreased but concentrated in a few days only. According to the United Nations Environment Programme (UNEP, 2007) the most important implication of rainfall concentration is the increase in the intensity of storms, which is 10 per cent per decade.

In a broader sense, a linear trend of rainfall decreased by 7.5 per cent in South Asia from 1900 to 2005, while drought frequency increased over time. Particularly, in the tropics and subtropics, droughts have become common since the 1970s according to the fourth assessment report of the IPCC (IPCC 2007). Analyzing the length of droughts in South Asia Dai (2011), using the Palmer Drought Severity Index, points out the key factors that cause prolonged droughts. These factors are increased temperature, decreased land precipitation, and enhance evapotranspiration. Moreover, 50 per cent droughts associated with the EI Nino, and the successive nature of droughts come with their own implications. For example, these disasters led to sharp decline in water tables, crop failures, and mass starvation. A recent study by Yumul et al. (2011) brought attention to the concept of the cyclone. They identified that climatic and non-climatic events in combination with cyclones have made the South Asian coastline extremely vulnerable to coastal flooding, and would result in substantial economic damages and fatalities.

Moreover, reliable regional climate change projections are now available with the advancement of modelling and understanding of the physical processes of the climate system. The most dependable projections are made by the IPCC (2007), which shows warming in South Asia is likely to be above the global average. However, the climate impacts for South Asia will vary heterogeneously. Some of the countries will experience more intense flood risks, while others have drought risks due to less rainfall. Moreover, different sectors, locations, and populations will have different impacts. For example McGregor et al. (2005) shows that higher temperature will affect rice and wheat yield in tropical regions of South Asia since these crops are grown on their temperature tolerance threshold. Angling differently, Schwierz et al. (2010) explain that the rise in temperature during the 20th century will change soil moisture status causing incidences of pests and diseases.

Finally, the regional economies of South Asia are endowed with great rivers, which are considered their lifeline. Higher temperature and glacier melting has serious repercussions in the form of the river over flooding. Giertz et al. (2006) explicated that temperature increase has huge implications for water availability on agricultural dependent masses. Huq et al. (2004) further highlights that semi-arid and arid areas are particularly exposed to the impacts of climate change on freshwater. Kundzewicz et al. (2008) explain that agricultural irrigation demands in arid and semi-arid areas is estimated to increase by at least 10 per cent for an increase in temperature of 1°C. These processes typically generate concerns for the small-holder with low financial and technical capacity to adapt to climate variability and change.

2.4 Implication of Climate Change on Agricultural Production

“Most of the people in the world are poor, so if we knew the economics of being poor we would know much of the economics that really matters. Most of the world's poor people earn their living from agriculture, so if we knew the economics of agriculture we would know much of the economics of being poor” (Shultz, 1979).

Agriculture has always been one of the important means of producing food for human consumption. Therefore, it has been granted a fundamental role in human welfare. Human communities, no matter how sophisticated, could not ignore the importance of agriculture as an economic activity; over time, humans have adapted dynamic agricultural systems and practices. Agricultural systems have been created, shaped, and maintained based on diverse natural resources, and local management practices. Presently, agriculture besides farming includes forestry, fruit cultivation, dairy, poultry, mushroom, bee keeping, etc. (Alexandratos, 1999; Badgley et al., 2007; Craig et al., 1997; Ruttan, 2002; Tilman et al., 2002).

The agricultural sector is derived and shaped by various factors. Farrington et al. (1997) identified a set of factors that have a prime influence on agriculture production. They include market fluctuations, changes in domestic and international agricultural policies, management practices, terms of trade, the type and availability of technology and extension, land-use regulations, and biophysical characteristics. Despite these aforementioned factors Rosenzweig and Hillel (2000) acknowledged that defining a characteristic of agriculture is its reliance on natural resources, as it consumes 70 per cent of global freshwater and occupies 40 per cent of land area. These distinguishing features nailed it on the interface within ecosystems and society. Dependence of agriculture on climate is evident. According to Dewalt (1994), agriculture was perhaps the first sector from human endeavors, where humans realized the existence of a strong nexus between agriculture and climate. Given its inherent link to natural resources, agricultural production is also at the mercy of uncertainties driven by climate variation, including extreme events such as floods and drought (Williams et al., 2006).

Looking at the inherent linkage between agriculture and climate simplifies its pronounced complex nature. Analyzing the sea saw weather pattern Adams et al. (1998)

expounded that agricultural activities would be under the dominant influence of distinct and comprehensive rhythm of the seasons. In a similar vein, Baethgen (2003) illustrated the primary conduits of climate change impacts. He found that projected effects of climate change will manifest steadily in changes of land and water regimes. Moreover, Berry et al. (2006) illustrated that climate change is expected to result in high frequency and intensity of floods and droughts. Additionally, long-term water resource shortage, worsening soil water condition, disease and pest outbreaks will also occur. In the interaction of agriculture with global environmental change vulnerability of agricultural production remains the critical issue; as climate change increases the frequency of extreme climate events (Reidsma et al., 2010).

The production of agriculture is extremely sensitive to climate change, hence the vulnerable nature of agriculture has been extensively discussed in the literature. The vulnerability is defined as “the degree to which a system is susceptible to and unable to cope with, adverse effects of climate change, including climate variability and extremes” (Nelson et al., 2010). Examining the agricultural vulnerability to climate change Adger (2006) demonstrates that crop yield is sensitive to elevated temperatures if the adaptive capacity of the farmers to such exposure is low. Moreover, Jones and Yohe (2008) exemplify that the degree of climate change effects reflects the sensitivity of agricultural production systems. Thus, sensitive systems are more elastic to climate and can be significantly affected by minor changes in climate. According to the theory of vulnerability, agricultural vulnerability is inevitable because of three basic components: exposure, sensitivity, and adaptive capacity. It implies that a system is vulnerable if it is exposed and sensitive to the effects of climate change, and at the same time has only limited capacity to adapt. On the contrary, a system is less vulnerable if it is less exposed, less sensitive, or has a strong adaptive capacity. (Janssen et al., 2006; Nelson et al., 2010; Smit & Wandel, 2006).

Looking at the climate sensitivity and crop yield link Rosenzweig et al. (2001) found that tropical regions of the world with agrarian economies are more exposed to harmful effects of climate change. Thus, these regions are expected to experience higher losses in agricultural productivity because anticipated productivity potential of agricultural land begins to decline with climate change. Additionally, examining constraints of agricultural production Downing et al. (2005) highlight that the vulnerability of agriculture is likely to be acute in light of technological, resource, and institutional constraints. In contrast, some beneficial effects of climate change have been expected, particularly in temperate regions (Eakin & Luers, 2006; Mendelsohn & Dinar, 1999).

Agricultural systems, currently subjected to extreme climatic inter-annual variability, are likely to become even more vulnerable. Similarly, drastic changes in economic conditions have made them more vulnerable under expected climate-change conditions. Impacts of climate variability and change generally can be described quantitatively by changes in biophysical indicators (e.g. agricultural productivity with regard to crop yields) or by socio-economic indicators (e.g. agricultural income from crop production). (Adger, 2006; Eriksen & Kelly, 2007; Füssel & Klein, 2006; Hinkel, 2011).

Likewise, the impacts of climate change on agriculture can be broken down into two border categories. First is the biophysical effects on production and yields, the second is the economic outcomes including prices, production, and consumption changes. Much of the work to access the impact of climate change on agriculture has been done. The early studies focus, however, on the vulnerability of the sector. The general consensus of the literature shows that climate change is contingent on a wide range of local environmental and managerial factors. To separate the set of key features, one can come across biological conditions, knowledge and awareness of changing climate, management regimes objectives and support, and the ability of key stakeholders to undertake necessary steps to address climate concerns. In a sense, climate change uncertainty presents an additional problem that farmers have to address subject to financial constraints.

2.4.1 Physical Implications

Starting with the physical effects of climate change on crops, Hulme et al. (1999) identified that distribution of agro-ecological zones will change due to anticipated changes in temperature and precipitation. Moreover, Soil moisture content largely depends upon temperature and precipitation, which consequently affects the length of growing seasons across the globe. Conceding that fact, researchers like Parry et al. (2004) expounded that higher temperature and low rainfall will increase irrigation demand in the agricultural sector. Moreover, in the semi-arid, tropics and subtropics regions, the likeliness of drought stress will increase substantially. Thus, most of the agricultural land will become unsuitable for cropping (Alongi, 2008).

Although agricultural production is vulnerable to climate change, impacts of climate change on the agricultural sector largely depend on the physical location or region. For example Rosenzweig and Parry (1994) state that temperate regions of the world witnessed the positive effect of climate change on agriculture. In contrast, agricultural production in tropical regions will be significantly affected by growing temperature conditions, especially in areas where temperature are close to the optimal level for crop growth (Harrington et al., 2001; Maracchi et al., 2005; Mendelsohn, 2000; Motha & Baier, 2005).

The anticipated impact of climate change on agriculture can be positive or negative; however, the severity of the impacts depend on the agricultural system, locality, and adaptation capacity (Falloon & Betts, 2010). Table 1 summarizes the positive and negative impacts of climate change.

Table 2-1 Climate Change Impacts on Agriculture

Climate Change	
Positive impacts	**Negative impacts**
Increased productivity by warm temperature Possibility of growing new crops High CO_2 enhance productivity Accelerated maturation rate Longer growing seasons	Insect infestation Crop damages from heat Planning uncertainties Land degradation Higher weed growth Reduce efficiency of herbicide/pesticides Extreme events

Source: Extracted from the literature

In essence, it has been found that negative effects overwhelmingly outweigh the positive effects of climate change. This will put unprecedented pressure on global food systems in the coming decades (Schmidhuber & Tubiello, 2007; Turral et al., 2011). Various agronomic studies show consensus on the explanation that higher concentrations of carbon dioxide (CO_2) will facilitate the rate of photosynthesis and water use efficiency. These effects are strongest for crops such as wheat, rice, maize, millet, and sorghum. The findings of Reilly et al. (1987) and IPCC (2001) are considered prominent in this regard. Both the studies found that escalation of atmospheric CO_2 is expected to yield a positive impact on agricultural productivity by 10-30 per cent. For the water use efficiency, Wallace (2000) suggests a similar range of productivity increase. In contrast to that, a very recent study by Schaible and Aillery (2012) contradicted the IPCC findings. They argued that on one hand, higher CO_2 concentration will bring positive effects on yield but on the other hand, net results may be moderated by the pest and weed infestation costs.

Similarly, water availability is another factor primarily linked with agricultural production. Numerous climate studies suggest that precipitation and growing season length are critical in determining positive or negative effects of climate change in agriculture (Fischer et al., 1995). Climate change will affect the overall water cycle and affect availability and demand of water resources. The changes in precipitation or snow melting will disturb the entire hydrological system by affecting quantity and quality of water. In the same way, climatic variability and the increased frequency of extreme events such as droughts and floods can cause agricultural losses. Higher drought frequency is likely to insert pressure on water supplies. In contrast, the upsurge in rainfall intensity can lead to a higher rate of soil erosion and land degradation. With equivocal climate change forecasts about how extreme events are expected, adjustment costs are likely to be higher with greater rates of change (Beniston et al., 2007).

To summarize, agricultural production largely depends upon the biophysical impacts of climate change, as mentioned above. Thus, it is vulnerable to climatic parameters. Climate change is expected to impact the agricultural sector in multiple ways, such as increased variability in temperature (Aggarwal, 2008; Asseng et al., 2011; Barrios et al., 2008; Wheeler et al., 2000), changes in rain patterns and water availability (Ines & Hansen, 2006; Sultan et al., 2005), frequency and intensity of extreme events (Beniston et al., 2007; Rosenzweig et al., 2001), pests and diseases (Ocuin et al., 2008), sea-level rise (Pfeffer et al., 2008; Rohling et al., 2008) and soil quality (Kibblewhite et al., 2008; Lal, 2004b). Figure 2-2 summarizes all the climate factors affecting agricultural production. It also shows the direction and linkage of all the factors with agricultural production.

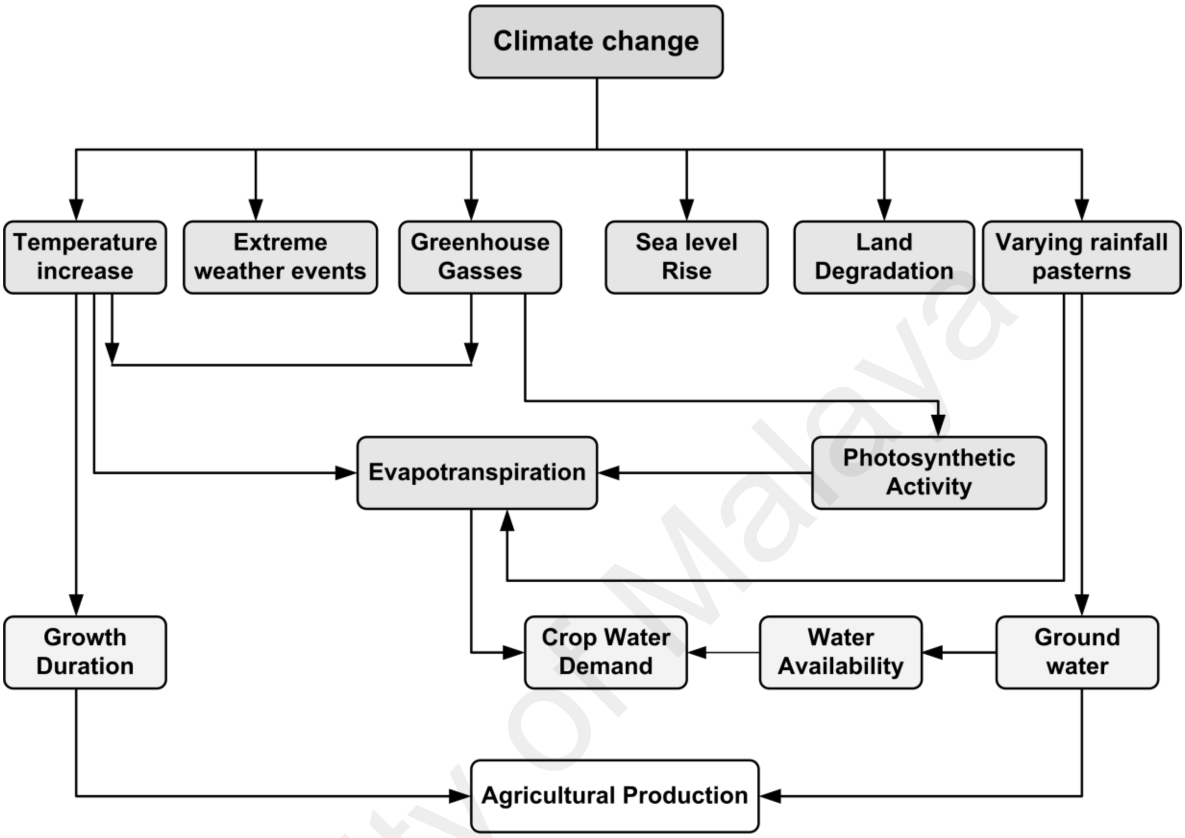

Figure 2-2 Climate Variables Effects on Agricultural Production

Source: Compiled from the literature.

Agricultural production has been changing continuously due to the aforementioned factors. Crop production will decrease with increasing atmospheric concentrations of GHGs; coupled with varying precipitation patterns and increasing temperature. This, in turn, modifies agricultural farming systems; consequently, the global agricultural production will decrease (Adams et al., 1998; Solomon, 2007).

2.4.2 Economic Implications

As discussed in the previous section agriculture arguably has a high dependency on climate, however, it is one of the most important sectors of the economy. Given the fundamental role of agriculture in human welfare, concerns emerge regarding the potential effects of climate change on agricultural production. In the production of agricultural commodities, social and environmental factors are equally important. Examples of the environmental factors include temperature, rainfall pattern, extreme weather events, heat waves, sea level, droughts, and floods. Changes in all these factors will severely affect agricultural production because it has high vulnerability and meager resilience. Provided the inherent association between environmental conditions with agriculture, its production is also at the mercy of uncertainties, driven by climate variation (Rosenzweig et al., 2008).

In the context of production theory, agricultural production depends upon natural inputs called “natural capital”. It is a key factor that determines the answers to fundamental questions like; what kind of crops can be grown? what will be the yield? how many crops can be grown per year in a certain location (Nordhaus, 1994)? Similarly, the literature on economic impacts of climate change so far, are inclined to focus on production and productivity in the agricultural sector (Goklany, 1995; Mendelsohn & Dinar, 1999). According to Reilly and Hohmann (1993), economic welfare has a close connection with agricultural production, and due to anticipated changes in climate, the welfare of agricultural production becomes uncertain. Angling differently, O'Brien and Leichenko (2000) argued that since climate itself is a resource, and can intervene in the production of other critical resources like agriculture, it therefore has serious impacts on the economic welfare of agriculture-based economies. This motivated a number of economic assessments of the effects of climate change on agriculture in the late and early nineties.

Early estimations of agricultural production under projected climate change studies shows a massive reduction of grain production in the near future (Darwin, 1999;

Olesen & Bindi, 2002). However, more recent studies reflect that agricultural supply is likely to be robust in the face of moderate warming, yet significant losses are expected worldwide due to severe warming (Nordhaus, 2007).

In the case of developing countries and particularly agriculture-based economies Mirza (2003) expounded that the economic vulnerability has intensified thanks to climate change. Schlenker and Roberts (2009) drew attention to the influence of climate change on the increasing rate of crop production damages in most of the developing countries with agrarian economies. In a similar manner Bindi and Olesen (2011) argued that conceptually, the initial economic effect of climate change on agriculture is the reduction of yield. Therefore, a number of researchers examine the economic impacts of climate change on agriculture by estimating farm value of agricultural productivity.

The reduction in agricultural production will increase the risk of hunger to a number of people. Analyzing the impact of natural resources on agricultural output Fischer et al. (2005) established a nexus between low agricultural GDP, average crop yield, and natural capital. They found that the health of natural capital will determine agricultural output as it has a direct influence on crop yield. Evaluating the impacts of climate change on agricultural GDP Schmidhuber and Tubiello (2007) estimated substantial losses of agricultural GDP, especially given the relative size of the sector in GDP terms. Moreover, Deschenes and Greenstone (2007) demonstrate that climate impacts cause fluctuation in food consumption due to limited agricultural production and re-allocation of land for crop production and agricultural productivity (Ortiz-Bobea, 2013; Stone et al., 2013).

McCarl et al. (2008) explore another important connection between climate change and poverty. In their study, they argue that in most of developing countries agriculture is the bread and butter of poor households. Hence, reduction in agricultural

GDP tends to increase poverty. Heading in similar direction Easterling et al. (2004) explore that the adversity of anticipated climate impacts on the agricultural sector will exacerbate the occurrence of rural poverty. According to Tubiello and Rosenzweig (2008), poor agrarian economies with low capital are unlikely to withstand the additional pressure imposed by climate change. The ultimate impact of such conditions can be seen in higher inflation, low productivity, and stagnating yield of major food crops.

Numerous studies have done a comparative analysis of agriculture and other sectors for seeking resources. For example, the studies conducted by Rosegrant et al. (2003) and Trostle, J. (2010) affirm that climate change will not only decrease agricultural production but, there will be increased competition for resources with other development needs, such as infrastructure. Moreover, analyzing economic impacts of climate change Zilberman et al. (2013) explicate that climate change most likely reduces the production and yield of major crops in the coming decades. Such unprecedented modification will cause changes in the agricultural product supply, which results in higher food prices; because supply has a direct negative relationship with price ceteris paribus.

Many researchers have worked on assessing the role and influence of climate change on agricultural production (Brunner, 2002; Fisher et al., 2012; Mendelsohn, 2000; Piesse & Thirtle, 2009; Rosegrant, 2008; Tomek & Kaiser, 2014; Trostle, R., 2010). In this context Kurukulasuriya et al. (2006) provides systematic information about the damaging impact of climate change on agricultural production in developing countries using cross-sectional data. Similarly, Piesse and Thirtle (2009) talk about food supply and food shortages due to low production of agricultural commodities. Brunner (2002) discussed volatility in agricultural commodity prices linking with production shocks. In their views, climate change exacerbates volatility of agricultural commodity prices. Food and commodity prices have risen and are expected to increase further due to instability in production quality and quantity due to climate change (Tomek & Kaiser, 2014). Higher agricultural commodity prices stimulate the producer to produce more and this results in a new equilibrium level of price and quantities. In the long run agricultural crop yield and acreage will change, and the climate will shape the households decisions regarding agricultural production i.e. what they can grow and how efficiently they can do it (Howden et al., 2007; Tubiello & Rosenzweig, 2008).

It is also important to note that finding studies assessing the relation between crop yield and climate change will vary across regions; therefore, price changes will also vary in the same way. Rosegrant (2008) suggested that countries located in tropical and subtropical (developing countries) zones were badly affected by the food price hike because their imports will increase substantially. However, in the context of the globalized world, global agricultural commodities supply influence the agricultural prices worldwide (Rosenzweig et al., 2007) .

Deliberating the exclusive connection of climate change with food prices Cotula and Vermeulen (2009) argued that on the one hand an unprecedented rise in food prices will adversely affect consumers. On the other hand, producers will gain from the higher prices. The consumer will reduce their consumption and shift to cheaper substitutes. Relating areas under cultivation and producer decision Thompson and Scoones (2009) illustrate that although climate change degrades agricultural land, producers will increase the area under cultivation due to the price increase. However, this increase in the area of cultivation is connected with the producer gain from price hikes instead of productivity increases. Thus, in the short run climate change will increase the prices and volume of agricultural production, particularly agricultural raw material and food commodities. In any case, the total welfare will be reduced as a resulting decline in the total supply (Chang, 2002).

As a matter of the fact climate change affects the production and consumption decisions. Similarly, it has profound effects on global food security. In general, food security has four dimensions namely; food availability, food accessibility, stability in availability, and utilization. It is expected with high confidence that climate change will shake all the components of food security. Moreover, the poorest regions will be exposed to the highest degree of instability in food production and availability (Schmidhuber & Tubiello, 2007). In the same way, various researchers show the indirect linkage of climate change with several economic factors, which is a link with agriculture. This factor includes trade and foreign-exchange earnings (Dobó et al., 2006; Thompson & Scoones, 2009), aid and investments (Cotula & Vermeulen, 2009; Greenhalgh & Sauer, 2003), and production/consumption patterns (Tobey et al., 1992; Trostle, R., 2010).

Currently, changing the climate and depleting natural resources are continuously putting pressure on agricultural systems to produce sufficient food, feed, and fiber to meet the increasing demand. Various studies explore the impact of climate change on agricultural production, envisaging various aspects. These studies mention multiple factors which have influenced the nature of climate change impacts on agriculture. However, none of these studies have looked at the disaggregated impact of climate change on agricultural subsectors through the lens of economic damages. The research presented here will analyze this aspect of climate change connection in the agriculture sector.

2.5 Exposition of Climate Change Responses

Mitigation and adaptation constitute two different approaches for dealing with climate change. All the policies formed to reduce the impact of climate change comprise of both approaches. Before we discuss mitigating in detail we briefly introduce an adaptation of climate change.

2.5.1 Adaptation

Climate change adaptation can be defined as “actions that people and institutions take in anticipation of, or in response to, changing the climate. This includes changes to things they do, and/or the way they do them.” Adaptation is considered an adjustment of natural and human systems in response to actual or anticipated impacts of climate change in a way that moderates harm or exploits beneficial opportunities (McCarthy, 2001). According to Adger (2006), adaptation responses disentangle into two modes: reactive adaptation and proactive adaptation (or anticipatory). When adaptation measures are considered important after the effects of climate change then it is a reactive adaptation. However, anticipatory adaptation emerges without any visible climate change evidence.

It is important to note that researchers like Smit and Wandel (2006) argued that adaptation adjustments enhance the viability of social and economic activities to reduce its vulnerability to climate change. Furthermore, in views of Janssen et al. (2006), it includes all adjustments in behavior or economic structure that reduces the vulnerability of society. Reenberg et al. (2008) suggested that the effectiveness of adaptation depends upon the right incentive, knowledge, resources, and skills to adapt efficiently. Additionally, Luers et al. (2003) expounded that private adaptation will occur and tend to be efficient as long as the costs and benefits of adapting are borne by a single decision-making entity, and government acts as a facilitator. Moreover, debating on the benefits of climate change adaptation researchers like De Bruin, K. C. et al. (2009) illustrated that benefits of adaptation to climate change can be evaluated through generic principles of policy appraisal seeking to promote equitable, effective, efficient and legitimate action harmonious with wider sustainability.

Indeed, the significant role of adaptation as a policy response has been recognized internationally. The United Nations Framework Convention on Climate Change

(UNFCCC) states that parties are “committed to formulating and implement national and, regional programs to facilitate adequate adaptation to climate change.” In view of the immense diversity of agricultural practices[3] a large array of adaptation options are possible. Adaptation decisions can help in the decision making of farmers, agribusiness, and policymakers with short-term tactics to strategic implications (Fankhauser et al., 1997; Smith & Lenhart, 1996).

The evidence of strong climate change trends is unequivocal, with the likelihood of further changes as well. Being inherently sensitive to climate conditions, agriculture is the most vulnerable sector to the risks and impacts of global climate change (Parry & Carter, 1989; Reilly & Schimmelpfennig, 1999). Adaptation has its significance in any policy response to climate change in this sector, some studies show that climate change has serious consequences for agricultural production, communities, and economies in the absence of adoption measures (Barnett & Mahul, 2007). However, adaptation can reduce vulnerabilities and generate numerous opportunities (Wheaton & Maciver, 1999).

In order to address the question, what is it that agriculture is adapting to? it is important to identify climatic and non-climatic factors that influence climate sensitivity of agriculture. Additionally, the nature of stimuli and vulnerability of system determines the applicability of any adoption option (Bryant et al., 2000; Pittock & Jones, 2000).

In agriculture various options of adaptation have been suggested to alleviate adverse impacts of climate. These adaptation measures include a wide range of form, scale, and participants (Skinner & Piek, 2001). However, they represent choices of

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[3] Agricultural practices are diverse because they are linked with wide range of climate and other environmental variables; cultural, institutional, and economic factors; and their interactions.

potential adaptation measures instead of ones actually selected. Additionally, various impact analysis assumes certain adaptation measures, although the process of adaptation remains unclear (Chiotti & Johnston, 1995; Fankhauser & Tol, 1997).

Cascading adaptation decisions depend upon the adaptive capacity of the agricultural system at all scales. Adaptive capacity refers to the potential ability of a system to successfully respond to climate change. Nonetheless, building adaptive capacity involve climate change information communication, awareness of potential impacts, maintaining well-being, protecting land, maintaining economic growth, and exploration of new opportunities (Adger et al., 2009). To enhance the adaptive capacity of the most vulnerable societies and sectors, identification of general determinants of resilience is emerging as a new research agenda. These determinants include the social capital of societies (Gargiulo & Benassi, 2000), the flexibility in government institutions (Pelling & High, 2005), ability of the private sector to grasp opportunities associated with climate change (Furgal & Seguin, 2006), and the health status and well-being of individuals and groups faced with the impacts of climate change (Adger, 2010).

Likewise, picking out the institutional and technological conditions that promote broad-base and equitable adaptation is the key. Therefore, facilitating adaptation, role of collective action is an important issue where lessons can be learned from political ecology, and other theoretical insights (Thomas et al., 2007). It has been suggested, accordingly, that the size of the group undertaking the collective action, the homogeneity of the decision-making group, and the distribution of management benefits are important in determining the ultimate success of collective management(Agrawal, 2010) .

Irrespective of motivation for adaptation, adaptations can generate short-term or long-term benefits. However, in the presence of longer timeframes, it may also generate costs. Additionally, with any ineffectual and unsustainable anticipatory action, adaptations may amplify the impacts of climate change. Moreover, climate stress can be increased by the adaptation of non-climate drivers. Because, on one hand it requires a thorough knowledge of the size and the regional distribution of damages while, on the other hand, precise assessment of the cost/effectiveness of alternative policies and of their strategic complementarity or trade-off (Hertin et al., 2003).

In sum, analyses of the economic costs of adaptation also highlight adaptation limits that are absolute and objective. Taken altogether, the specific goal of adaptation is to ensure the survival of livelihoods, lives, and culture during environmental changes. It aids the resilience against environmental fluctuations. It is an effective tool to absorb the environmental changes but largely depends upon the adaptive capacity of the economy or sector. The fact is adaptive capacity is greater and efficient when the nation has a stable and prosperous economy (Schipper, 2007) .

2.5.2 Mitigation

The IPCC recently concluded that warming of the climate system is unequivocal. Human activities have been "very likely[4]" responsible for the observed increase in global average temperatures since the mid-twentieth century (Dominguez et al., 2010). Mitigation reduces the burgeoning impacts of climate change by reducing emissions or capturing carbon. These activities try to restrict the extent of long-term climate change impacts. It also includes prior actions aimed to reduce anthropogenic emissions of greenhouse gasses (GHGs) (Bosetti et al., 2009).

Examples of mitigation can be seen by opting low-carbon energy sources such as renewable and nuclear energy, and building additional "sinks" to eliminate the greater

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[4] Very likely' in IPCC terminology means greater than 90% likelihood.

amount of carbon dioxide from the atmosphere through actions such as forestation and expansion of green belts. Climate engineering is also another method for climate change mitigation (Canadell & Raupach, 2008). It cannot be denied that climate change is a global commons. This ‘‘commons’’ problem suggests that top-down international treaties be required ultimately to achieve substantial climate change mitigation. The UNFCCC insist all the countries put forward collabourative efforts for mitigating climate change. They further argue that such collabourative efforts will be cost effective and at the same time developing countries will reap the benefits in the form of financial and technological support (Halsnæs, 1996).

The UNFCCC is tackling the controversial issue of “burden sharing” relating to the differentiation of national commitments to limit GHG emissions, before and after signing the agreements. However, to address the issue a variety of proposals were launched. Finally in the mid-1990’s policy negotiations resulted in the signing of the Kyoto Protocol. The developed (Annex I) countries agreed to mitigate GHG emission while this commitment is still needed to be signed by the developing (Non-Annex I) countries (December 1997).

The quantity controls debate on global climate change policy is contested by several researchers. For example Dalton et al. (2007) argue that it is in the limelight due to its political appeal. He emphasizes that price control measures to reduce global emissions are more efficient. Similarly, Lampert and Ziebik (2007) in an empirical study explicated that welfare gain from the optimal price policy is five times higher than the optimal quantity policy. However, the mitigation potential synergy between current climate change policies, sustainable development, and improvement of environmental quality will likely lead the way forward(Smith et al., 2008).

Until the Third Conference of the Parties (COP-3) in Kyoto, the focus of the discussion remains the elabouration of the Protocol, while GHG mitigation commitments received little or no attention. Prato (2010) suggested that for achieving the ultimate objective of the UNFCCC extra reduction of GHG emission by Annex I countries, gradual participation of the Non-Annex I countries is needed. Ultimately, it would prevent anthropogenic interference with the climate system by stabilizing GHG concentration in the atmosphere (Sijm et al., 2001).

On the charter of UNFCCC, the key global agreement on climate change is ratified in 2002 with the aim to "prevent dangerous anthropogenic interference with the climate system (Leiserowitz, 2005) . In 2010, the UNFCCC member nations agreed to restrict the future global warming below 2.0 °C (3.6 °F) relative to the pre-industrial level. Canadell and Raupach (2008) suggested that for achieving said objective necessitates reversion of growing global emission trend by 2020. Nevertheless, Weiler (2012) suggested that continuation of the decreasing trend in emission by 30-50 per cent as compared to 1990 levels will serve the purpose. In response to such actions the United Nations Environment Program and International Energy Agency disavow that strategy and believe that it is a fairly inadequate method to attain the 2°C target (Fankhauser et al., 2010; Weitzman, 2009).

2.6 Limitation of Response Action

Climate change is a reality, and adaptation and mitigation are inevitable measures to cure its catastrophic effects. However, certain limitations exist in both approaches, which have significant implications for developing agrarian economies. These limitations emerge due to the indolent characteristic of people, nature of the system, and the operational way of the involved people.

The limitation associated with adaptation can take any form from natural, technological, economic, social, or formal institutional. The range from ecosystem to geographical thresholds constitute natural limits, where abrupt climate change generate adaptation limits by altering the physical environment. Similarly, the impact of unexpected climate change generates foundations for shifting ecosystem regime thus, generates limits in economic and social adaptation. It is also important to note that communities that have a direct dependence on the ecosystem will be most affected by such limitations (O'Brien et al., 2006; Scheffer et al., 2001).

Addressing technological barriers of adaptation Reeder et al. (2009) proposed that lack of a hard engendering structure along with the limitation of small equipment can hinder the adaptation. Moreover, Moser and Ekstrom (2010) argued that economic and social barriers also limit the possibilities of adaptation. Addressing the financing capabilities of low-income countries Linnerooth-Bayer and Mechler (2006) argued that financing adaptation, particularly in agriculture, is beyond the capabilities of public and private authorities due to lack of financial capital. Similarly, various studies suggested that ethics, knowledge, risk, and culture are key aspects of social barriers to adaptation (Jones & Boyd, 2011; Löf, 2006).

Despite the aforementioned loopholes many advocates of strengthening adaptation efforts and policies act like fanatical lovers. They praise the many positive aspects of adaptation strategies to the point of mystification but deny the difficulties becoming apparent when taking a closer look. Acknowledging the fact that adaptation can reduce potential dangerous impacts of climate change by causing a fair reduction in key vulnerabilities; it demands a technical, financial, and institutional capacity that most of the developing countries don’t possess (Eggers & Kaplan, 2009).

Since the developing countries have fragile economies, they experience critical limits to corresponding climate change phenomena. Among these concerns related to adaptation decisions, magnitude, and rate of climate change in different part of the world may turn out to be unprecedented in human history. Likewise, the smooth climate changes and relative adaptation can be interrupted by a sudden discontinuity in climate or close sequence extreme weather event which may undermine the ability to cope (Folke et al., 2004).

Despite adaptation, the other most contentious issue is the divide between the interests and obligations of developed and developing countries towards GHG's emissions. Based on the equity standards developed countries should initiate their efforts to reduce the emission of GHG's because they are the source of the most past and current emissions (Canadell et al., 2007; Garnaut, 2008). However, reducing GHG emission in developing countries is a fundamentally different challenge. Van Vuuren et al. (2011) illustrate that with far below income level and poor quality of life, developing nations can't stick to the pledges made on Kyoto Protocol or UNFCCC etc. Reducing emissions will hinder their growth, which is not a viable option for developing countries.

Additionally, mitigation of GHG's is also quite challenging for the developing countries. To mitigate CO_2 emission the growth of global economy must be a limit to zero. However, zero growth will induce global economic crises. VijayaVenkataRaman et al. (2012) acknowledge that zero growth will eventually cut back CO_2 emissions; however, conciliating environmental issues and desirable development of global economy still remains vibrant (Yan et al., 2005). On the other hand, the UNFCCC estimates that over $65 billion in additional mitigation investment and financial flows will be needed in developing countries by 2030, while McKinsey suggests that investment flows could exceed $100 billion by 2015 (McKinsey, 2009).

Accepting emission limits, however, is not the only measure of whether a country is contributing to climate change mitigation. Efforts that serve to reduce or avoid greenhouse gas emissions, whether or not undertaken in the name of climate protection, nonetheless contribute to climate mitigation. These efforts can occur across virtually every sector of an economy. Thus, it is very likely that GHG emission will surpass in developing countries in the first half of the century since the binding emission targets are not viable for these countries. Accordingly, climate mitigation took the place of an outgrowth effort driven by local environmental concerns.

Given this limitation of adaptation and mitigation actions, this study seeks other possible ways to address the climate change issue. It is particularly important for agricultural economies to take bold and visionary measures on the national and international level to transform their economies into a more resilient form that can meet the challenges of climate change.

2.7 Technical Change and Climate

In the Post-Kyoto climate, regime technology is at the core of current discussions. The Bali Road Map[5] of 2007 considers technology development and diffusion as strategic objectives that trigger the debate about appropriate policies. In particular, developed countries improve environment friendly technologies, while fast-growing, emerging economies urgently require them to mitigate GHG emissions. For achieving the target of global CO_2 emissions cut back, the transformation of technology from advanced to developing countries are considered mandatory. Likewise, advance economics should

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[5] Participants at the 2007 United Nations Climate Change Conference in Bali developed a road map, known as the Bali Road Map, for negotiating a new climate agreement by the end of 2009.

encourage the investment in research and development (R&D) because on the one hand it will increase development rate of the global economy while on the other hand it will reduce global CO_2 emissions (Onishi, 2007).

Environmental policy discussions more and more concentrate on issues identified with technological change (Martin & Scott, 2000). This is commonly in light of the fact that the environmental consequences of social activity are mostly influenced by the rate and course of technological change. Additionally, environmental policy interventions can themselves make limitations and motivations that have critical impacts on the way of technological advancement (Smith et al., 2005).

The importance of technology to redress climate change is widely emphasized in literature. For example, Hamilton and Feenberg (2005) and Vielle and Viguier (2007) in their studies provide two reasons why technology is considered important for climate change analysis. Firstly, the anthropogenic contribution to climate change up to a historic context has been caused by the application of technology. The process of the transformation of economies and societies was facilitated by coal and gas jointly. Thus understanding the historical backdrop of technical change then assists us to discover the course of future specialized change. Secondly, a low carbon society demands massive development and deployment of new low-carbon technologies.

Binswanger (2001) suggested that in order to overcome the harmful effects of climate change structural changes in global economic activity are required. Additionally, technological changes that enable these activities should also be considered as they hold the potential to reduce the barriers of climate change mitigations. Moreover, Edmunds and Morris (2000) expounded the importance of technical change in economic analysis of climate change. In their empirical analysis, they prove that in the case of climate change existence of a market failure in R&D is additional with environmental externalities.

Hence, examination of policy interventions become important. However, without modelling the economic process of technical change this cannot be done efficiently (Hourcade & Robinson, 1996; Löschel, 2002).

Two decades ago climate policy modeling[6] was virtually non-existent. Currently, numerous models with impressive range and sophistication are geared to this purpose. Similarly, to model technical change, highly sophisticated simulation models are developed. The models project the environmental and economic outcomes as a result of technical change and indicate how the outcome would change under policies[7] formed to retard the rate of greenhouse gas accumulation (De Coninck et al., 2008).

These models tend to estimate abatement cost of CO_2 emissions of the world economy or specific country. The first policy models tended to concentrate on the cost side of the ledger, seeking to estimate the abatement costs to the world economy or particular countries of strategies to reduce CO_2 emissions (Manne & Richels, 1992). However, lately, integrated models are developed that can jointly consider benefits and cost of reducing atmospheric greenhouse gas accumulation (Morgan & Dowlatabadi, 1996).

Climate and economy models have been influenced by three strings of literature. Firstly, the changes in modelling are influenced by new endogenous growth theory. This theory takes knowledge and capital stock as pre-requisites for productivity, although findings based on empirical evidence are mixed. Secondly, learning curve literature highlights that reduction in unit cost will boost the production. In this case increasing returns to scale of the critical sectors of climate change must hold. This theory lacks solid

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[6] Nordhaus 1980, 1982. Pioneered the economic analysis of global climate policy.
[7] Such policies include carbon taxes, energy efficiency standards, and subsidies to afforestation.

theoretical underpinnings. Thirdly, top down and bottom up literature focus on the stock of knowledge by increasing returns to the scale with a special focus on the process of technical change. The combination of the two approaches makes important contributions to the current understanding of processes of technical change. This section of literature is often known as innovation literature and focus on the role of spillovers, uncertainty, and path dependence (Manne & Richels, 2004; Nordhaus, 2002b).

The relationship between climate and technical change is important in a number of different levels. According to the findings of Popp (2006) technical change can have a strong possibility to cause optimal near-term abatement if focused R & D expenditure results in technical change the abatement in near term will be slightly on the lower side. However, in view of Goulder and Mathai (2000) if the technical change results from learning by doing, more abatement will result due to more technical change. The growing body of literature covers the advances of technological change in the context of climate change. Mostly it is concentrated on the technical change that occurs as a result of policy, the indirect effect of market factors and control variables. On the modelling front, various examples can be found like Buonanno et al. (2003) and Van der Zwaan et al. (2002).

Though, the new generation of environmental-economic models treats technological change as endogenous, i.e. responding to socio-economic (policy) variables, e.g. prices, investment in R&D, or cumulative production. In the case of climate models which consider technology as endogenous, it will eventually present low costs of abatement, in comparison of conventional models with exogenous technological change. Endogenous technical change can be castigated in the model by five different ways; 1) Categorical illustration of some energy technology i.e. renewables, backstop, energy efficiency or some combination of these (2) Escalations in knowledge capital by rise in

R&D spending (3) Experience curves (4) Spillovers, from knowledge capital or inexperience curves and (5) Crowding out (Baker & Shittu, 2008; Karp & Zhang, 2006).

Incorporation of endogenous technical change has been challenging because it involves a finite set of idiosyncratic technologies that requires subjective judgment. It is also challenging to incorporate bottom-up data into top-down models (Webster & Watson, 2002). And last but not the least; it involves computational challenges to model endogenous technical change. Furthermore, due to the complexity of the technical change process, and lack of empirical understanding on the determinant of technical change it makes the process much more difficult (Jacoby et al., 2006).

In ecological economics, technical progress plays a much less prominent role than in neo-classical contributions. Ever since Hicks's articulation of the induced invention hypothesis (IIH) that price changes affect the rate and direction of technological advance, economists have tried unsuccessfully to put theoretical and empirical findings on its conceptual skeleton. Nevertheless, despite the fact that the IIH remains more a general principle than a fully articulated theory, induced innovation tends to be cited as a benefit of the regulatory intervention, especially in the environmental policy arena (Jaffe et al., 2005; Pearce, 2002).

Regarding technology, it can be asked how much technical progress is needed to prevent negative income growth or it can calculate fading resource inputs (Nordhaus, 1993). Technological change that increases in outputs without increases in productive inputs can lower the cost of GHG abatement policies through product innovations, i.e. higher energy-efficiency of existing and new products, and process innovations, i.e. higher energy efficiency of manufacturing processes, cost reductions in low-emission energy conversion and improvements in fossil energy conversion (Del Río González, 2009; Rehfeld et al., 2007).

Climate change is thus the litmus test of induced technical change (ITC) because the costs of mitigation policies and the potential for technology to alleviate them dwarf those of other environmental problems. Technological change is perhaps the single most important source of uncertainty in forecasting the macroeconomic cost of limiting GHG emissions. There is considerable debate over the impact of technological change on the cost-minimizing trajectory of GHG abatement. Some argue for postponing emissions cuts to allow for the development of new substitution possibilities that facilitate cheaper and more rapid abatement (Siegel et al., 2003) while others advocate undertaking aggressive abatement to induce the development and adoption of technologies that mitigate abatement costs (Rennings et al., 2006). The former wait-and-see" approach assumes that new technology development follows an autonomous rate of advance of which emission standards should be cognizant while the latter act-now" approach assumes that technological change is both amenable to inducement and has a mitigating effect on policy costs.

2.8 Climate Change: Methodological Approaches and Issues

The various models have been applied to assess the impact of climate change on agricultural production. Each model presents a different level of complexities and competencies in relation to the aspect considered for analysis. The following section briefly discusses the peculiarities for each approach.

2.8.1 Crop Simulation Approach

In crop simulation approach, the effect of climate change was analyzed by considering crop physiology only. In this approach comparison between crop productivity for different climatic conditions is carried out for a specific crop (Eitzinger et al., 2003; Torriani et al., 2007). This approach is by and large considered agricultural because it only focused on the biological and ecological consequences of climate change on crops and soil. Though this approach is a useful and easy measure to identify the impact of climate on a certain crop, it has some drawbacks. First, it does not account for farmer behavior, for example how the farmer will behave under extreme climate conditions. Secondly, it considers management practices as fixed, therefore, technical change can't be incorporated in the simulation process. Lastly, it is site and crop specific i.e. only a single crop or location can be considered for experimental purposes (Seo et al., 2009).

2.8.2 Production Function Approach

In contrast with the crop simulation approach, the production function approach is forward looking. In this approach yield sensitivity of crops to climate is estimated by empirical yield models (Eitzinger et al., 2003; Isik & Devadoss, 2006). In this approach, agricultural production is considered dependent on soil-related and climate variables. Therefore, these factors are considered independent variables in the production function. In this approach, economic dimensions are given secondary importance, despite the fact that this approach generates important information for the larger model, which considers the whole economy. Lhomme et al. (2009) use this approach to access the economic impact of climate change through the estimation of the economic production function. Finger (2012) evaluates economic effects of climate change by conducting agronomic analyses of empirical yield models through mathematical programming.

Similar to the crop simulation approach, the production function approach is also site and crop specific, which is a major weakness of this approach. Moreover, it endorses dumb-farmer hypothesis, which excludes adoption strategies for coping with the effect of climate change.

2.8.3 Ricardian Approach

To overcome the limitation of the dumb-farmer hypothesis, Mendelsohn et al. (1994) proposed the Ricardian model approach. The Ricardian approach considers adaptation to climate change as a “black box”, which is its principal characteristic. Seo et al. (2009) further explained that in this approach adaptation is addressed implicitly, hence the need for an explicit explanation of adaptation as an explanatory variable is not required.

The implicit consideration of adaptation could represent the weakness of this approach if adaptation strategies to climate change are considered core for analysis (Howitt et al., 2012; Qureshi et al., 2010). Recently, several types of research have attempted to overcome limitations in Ricardian approach. For example Oluwasusi and Tijani (2013) use proxies of adaptation strategies as an independent variable in farm survey data in the econometric model. Likewise, Gebrehiwot and van der Veen (2013) modeled adaptation as the dependent variable. This application of Ricardian approach increases the capability of estimations using available data.

Moreover, the Ricardian approach is suitable for sophisticated models that consider specific characteristics of the database (for example endogeneity, stratified samples, spatial correlation, and panel and time-series data). Additionally, different equation functional forms (e.g. linear, log-linear, quadratic, Box-Cox) different distributions for the error term (e.g. normal, Weibull, probit, logit) can also be hypothesized using the most suitable estimator (e.g. ordinary least squares, maximum likelihood estimator). Nevertheless, the ability to predict is strongly connected with the data quality and model specification.

2.8.4 General Equilibrium Approach

The aforementioned approached mainly focused on the agricultural sector, its specific branches, or crops without considering the relationships with other economic sectors. Numerous researchers revamped the existing approaches and developed the general equilibrium approach (Calzadilla et al., 2010). This approach examines economy as a complex system with interdependent components. On top of that general equilibrium, approach has an added advantage to capture global economy-wide changes, with the effects of climate change on economic sectors including agriculture.

This approach has a major weakness of considering an aggregate form of a sector characterized by different economic and spatial dimensions. For example, agriculture is considered an aggregate sector at national level, but it has its local considerations. Secondly, Kurukulasuriya et al. (2006) advocate that adaptation of climate change by the farmer is not addressed in every dimension.

2.8.5 Integrated Assessment Approach

To overhaul the limitations of all the approaches researchers developed integrated assessment approach. This approach is a combination of all the aforementioned approaches (Stanton et al., 2009). According to Prinn et al. (1999), the integrated assessment approach describes cause and effect of climate change by assimilating knowledge from diverse academic disciplines into a single framework. In doing this, policymakers can get insight information to formulate an efficient policy. Moreover, this method considers all the dimensions of agriculture simultaneously (Antle & Capalbo, 2001; Fischer et al., 2005).

Integrated Impact Assessment models (IAMs) of climate change are motivated by the need to balance the dynamics of carbon accumulation in the atmosphere and the dynamics of de-carbonization of the economy (Nordhaus, 1994). IAMs have become recognized instruments for policy makers providing useful information and scientific insights for climate policy. These models can be classified in a number of ways. For example, Toth (2005) divide them into (i) policy evaluation models and (ii) policy optimization models. The first group is formed by simulation models that take user-defined assumptions about a course of future policy and calculate the implications of the specified policy for all modelled variables of interest of the policy-maker (e.g. temperature change, ecosystem and agricultural yield changes, sea-level rise). Policy optimization models summarize the relevant boundary conditions in a set of defined parameters in a scenario, separate key policy variables that control the evolution of the climate change problem (e.g. GHG emissions, carbon taxes) and determine the value of these policy variables in an optimization procedure. Stanton et al. (2008) separate IAMs into (i) welfare optimization models models that maximize net present value of utility of consumption subject to climate change damages and abatement strategies; (ii) general equilibrium models models that represent the economy as a set of linked demand and supply functions for each economy sector; (iii) simulation models those based on exogenous scenarios about future emissions and climate conditions; and (iv) cost minimization models that identify the most cost-effective to a climate-economics model. However, most classifications of IAMs found in the literature allow for some overlap between sub-groups of IAMs, since there are models that fit into more than one classification.

However, the existing models used in the climate change debate in a different way: we split the economy module into three distinct sub-modules that better separate the models according to the emphasis they put on different aspects of the economy. These sub-modules are (i) the economic dynamics or economic growth module, in general represented by an applied or computable general equilibrium model (CGE) of the global (or regional) economy; (ii) the energy module, in most models constructed in a "engineering´ or bottom-up approach (iii) the damage module in which the interaction between climate variations and the impacts in the economy is modelled. The existence or not of combinations of these economic sub-models plus a climate module determine the classification we use. For example, we consider a fully integrated IAM those models that include all modules above: an economic growth model, including the energy sector, a damage module and a climate module. We name Non-CGE-type models those that do not include an optimization procedure of the economy. In general, non-CGE models include a climate module and a damage module, some also include an energy module, but all assume different scenarios for the world economy given elsewhere (e.g. IPCC scenarios). This type of models can also be considered as the policy evaluation models described by Toth (2005), or the simulation models named by Stanton et al. (2008). Finally, we name the CGE-type of models those models that focus on the optimization of the detailed characterization of the economy, including the energy sector. These models have been used extensively for analyses of the impact of carbon taxes and other policy instruments in the economy and resulting emission reductions. In general, the CGE-type of models is characterized by the absence of a proper climate module.

The main weakness of IAM models is their complex nature. Additionally, the interaction between agriculture with climate change is partially treatable, where the accuracy of the analysis is subject to the treatment of complex interaction. Another limitation is that productivity in this approach has been treated exogenously despite its strong correlation with climate variables (Moss et al., 2010).

In condensed form to assess the effects of climate change on agriculture, the choice of an appropriate approach depends on the following factors. First is the level of analysis needs to be conducted, for example, whole agricultural sector, a particular crop or branch of agriculture. Secondly, the scale of analysis and third is the phenomena used to measure the effects of climate change. Finally, the dimensions of agriculture with respect to which climate impacts are assessed are also important. Taking these points with previous arguments, the integrated assessment approach is best suited for analyzing climate impacts since, this approach simultaneously considers all the dimensions of agriculture (Biological, Social, and Economic). Moreover, it generates useful information for policy perspectives. Based on the measures to assess the impacts the following sections briefly describe the response actions for climate change.

2.9 Climate Change and Agricultural Production: Theoretical Exposition

The traditional view of climate change is forward by Milankovitch (1941) that climate is changing by it natural order, and natural climate variability is the result of natural processes. The natural variability of physical or biological systems causes pragmatic changes in natural processes. Many physical processes come into play as a response to these forces which is termed as “climate change”. If the feedback or response can be positive or negative likewise the climate response is also positive or negative respectively.

As discussed in the previous section, this view started to change in the late 80's and early 90's, when economists like Nordhaus (1992) and Sarmiento et al. (1998) postulated human interventions for contemporary climate change. Coining the notion of anthropogenic human influence, they consider human activities a major factor affecting the level of climate change. Congruently, a recent report by various international organizations proclaimed with a high confidence that the net effect of human activities has been warming climate since the industrial revolution. Several studies up until present day concluded that anthropogenic activities are dominating the causes of recent climate change rather than natural forces (Knutson et al., 2010).

Even with the established consensus of anthropogenic causes of global climate change, scientific debate continues on the issue of the relative size of the anthropogenic activities on climate change. Since the observed changes in climate and natural systems are unlikely to be entirely due to natural variability nor is it completely due to anthropogenic activities. Therefore, the changes in the climate system are further analyzed due to the distinguished features of natural and anthropogenic causes and given a new name of 'Attribution'. Combining both types of attribution is called 'Joint Attribution'; this laid the foundation of a new theory of climate change.

Congruently, Rosenzweig et al. (2008), briefly discussed the two different dimensions of climate change. Broaching on the subject of the importance of climate change, they explicated that climate is changing and will have serious repercussions in near future if remain unchecked. At the very outset, in their study entitled "Attributing physical and biological impacts to anthropogenic climate change", they expounded the difference between natural and anthropogenic causes of climate change. They accentuated that changing climate is more dangerous for those economies that are agro-based because the environmental factor is a direct input for agriculture production. In concluding their study, they asserted that anthropogenic climate change is having a significant impact on physical and biological systems globally and in some continents.

Adger (1999) highlighted one fundamental cord of climate change impacts which was equally important. He discussed climate change vulnerability of any economic segment (agriculture, industry, and services) is reflective of the exposure and sensitivity of that system to hazardous conditions. Moreover, the resilience of the system to recover from the effects of the perilous condition is an equally important determinant of vulnerability. It was this reason according to Ford et al. (2006) that systems with implicit adaptive capacities might be more productive despite the degree of climate exposure they exhibit. For McCarthy (2001) this not only augments the productivity of the economic segment but also core competency of the entire economy.

As a first step in the ecological-economic assessment of climate change and agricultural vulnerability, Fischer et al. (2002) described in terms of exposure to elevated temperatures, the sensitivity of crop yields to the higher temperature, and farmer’s ability to adapt to the effects of this exposure and sensitivity. Thus being a developing country, the agricultural sector of Pakistan has a low adaptive capacity and is a more vulnerable agricultural system to anticipated climate change.

Likewise, theories discussing the nature of agricultural production considered climate change a vital factor of production. According to a resource base view of Wernerfelt (1984), resources should have four characteristics; value addition, non-substitutability, rareness, and inimitability. In the context of production theory, Nordhaus (2008) expounded that agricultural production depends on natural resources called “natural capital”. According to Nordhaus (2008), natural capital is a key factor that determines the answers to fundamental questions like; what kind of crops can be grown? what will be the yield? how many crops can be grown per year in a certain location?

Epitomizing the same point Reidsma et al. (2010) argues that linkages between agriculture and climate are pronounced and often complex since agricultural activities continue to be under the dominant influence of distinct and comprehensive rhythm of the seasons. Climate change is expected to result in higher frequency and intensity of floods, storms, and droughts. Additionally, long-term water resource shortage, worsening soil water condition, disease and pest outbreaks, and sea level rise can be expected. In the interaction of agriculture with global environmental change vulnerability of agriculture to the future climate change remains the critical issue; climate vulnerability has been exacerbated by changing the incidence of extreme climate events.

Latching onto the production theory, it is revealed that the efficiency of agricultural production is impossible without the healthy condition of natural capital. According to Nordhaus (2008), climate change is continuously generating harmful effects on the natural capital which cause delayed agricultural production. In the context of the present debate over international agreements such as the Kyoto Protocol and the outcome of recent Paris declaration, uniform assessments of global impacts of climate change on food and agricultural production is of the utmost importance. Such quantified and spatial information provides important inputs that can underpin national and regional adaptive policies to mitigate the consequences of climate change and also facilitate international negotiations on climate change, taking into account the relative impacts in the context of their specific development needs and priorities.

The crowning point of theories related to agricultural production is that the agricultural sector is particularly vulnerable to manmade and natural climate change. Sustainable agricultural production depends on the viable natural capital vigor. Climate change not only hampers agricultural production but affects the entire economic welfare. Moreover, agricultural crop distribution and production are largely dependent on the geographical distribution of climate change. Global warming is significantly increasing the area with temperature regimes conducive to growth and production of agricultural crops, while it is impeding production in rest of the world which is largely underdeveloped.

2.10 Climate Change and Economic Damages: Empirical Evidence

The impact of climate change has been investigated thoroughly since the 1990's. However, most of the early research focused on the developed countries where data availability is not an issue and the challenges of climate change are well recognized. Most of the early studies were focused on the socio-economic damage costs of climate change. All these studies are considered as first generation climate analysis, and they mainly focused on the effects of doubling carbon dioxide (CO_2) concentration on the current economy. The comprehensive and prominent assessments in this areas were conducted by (Cline, 1996; Nordhaus, 1993; Titus, 1992).

Although first generation climate studies agreed on the effects of doubling the concentration of CO_2, the uncertainty in anticipated economic damages remain a controversial issue. For example, in view of Archer et al. (2009) estimating temperature change as a result of cumulative emission is also challenging. However, they agree with the default transient climate response (TCR) of the global-mean temperature change. It occurs at the time of CO_2 doubling for the specific case of a 1 per cent per year increase of CO_2. The study by Stern (2007) among many is a prominent example of it. In his reviewed results of environmental experts, he emphasizes on the facts that global warming is caused by the emissions of CO_2 and other GHGs. Similarly, the results of IPCC shows consensus on the Stern (2008) results. They found that since the industrial revolution global temperature has increased by about 0.6°C mainly because of increase in the concentration of GHGs in the atmosphere.

Moreover, if the GHG concentration is held fixed at 2005 level the world would still experience the estimated warming of 2.4ºC. This will disrupt the threshold agreed by many international organizations for dangerous anthropogenic interference (DAI) (Alcamo et al., 2007). In explaining the concept of DAI Hansen et al. (2007) claims that DAI is partially subjective, however, the additional global warming of 1ºC above the level in 2000 can produce highly disruptive effects.

The catastrophes effect of climate change is evident across all the sub-sectors of the economy. However, the agricultural sector is dependent on climate and economic factors, therefore, it is considered most vulnerable to climate damages. Since the effect of climate change on the agricultural sector is among the largest and best documented many efforts have been made to analyze the projected effects of climate change on agriculture. However, until 1999 developing countries have not got the desired attention in this realm of research (IPCC, 2001; Smit & Skinner, 2002).

Many of the empirical researchers characterized that agriculture is strongly influenced by weather and climate. Empirical studies revealed that climate change is expected to impact agriculture by potentially threatening established aspects of farming systems, yet provide some opportunities for improvements (Olesen & Bindi, 2002). The impacts of climate change on global agricultural productivity is based on the vulnerability of agriculture to its adaptive capacity. For example considering climate parameters as an important indicator of agricultural performance Battisti and Naylor (2009) illustrate that higher growing season temperature significantly affects agricultural productivity and farm incomes.

Correspondingly, taking mid and high latitude communities as case studies Maracchi et al. (2005) and Tuck et al. (2006) explains that cereal and cool season seed will be more productive under higher temperatures. They observed that crops like maize, sunflower, and soya beans could also become viable further at higher latitudes. Moreover, it was also found that the expected yield could increase by as much as 30 per cent by the mid-21st century. This shows a positive relationship between temperature increase and agricultural productivity (Alexandrov et al., 2002; Ewert et al., 2005).

Similarly, Fischer et al. (2005) explore the association between climate change and agricultural production in the coming century by focusing on temperature increase only. They simulated 64 per cent increase in potential agricultural land under warming conditions by the 2080s. Nevertheless, Ewert et al. (2005) computed that technological development could outweigh land increase effects, thus results in combined wheat yield increases of 37–101 per cent by the 2050s.

Nevertheless, crop yield varies with temperature increase, for example, the production of agricultural crop near temperature thresholds will be highly detrimental with immediate effects. For example, Canadell et al. (2007) examined the relationship between growing season temperature, precipitation, and global average yield of major crops by fitting in a statistical relationship. Results portrayed that since 1981 all the major crops exhibited combined losses of US$5 billion. This shows the negative relationship between agricultural production and temperature increase. In a similar research, Nelson et al. (2014) examined the sensitivity of agricultural production to climate change. They studied the symmetrical integration of different types of model, with the main focus on an economic component of the models. The findings of their study illustrate that global yield reduction will be 17 per cent with reference to a scenario with unchanging climate. Moreover, economic response reduces consumption by 3 per cent with major crop yield loss by 11 per cent.

A good chunk of empirical literature unveiled the impact of rainfall variation on the process of agricultural production. For example, Kurukulasuriya et al. (2008)

highlighted that variations in rainfall will have major impacts on the viability of dryland subsistence and irrigated crop production. Similarly, Benjamin (2012) suggest that varying rainfall pattern exert extra on crop yield growth. Likewise, variation in rainfall pattern, on the one hand cause flooding, which can wipe out entire crops over wide areas. On the other hand, however, lower rainfall will increase crop water demand globally by between 5 to 20 per cent by the 2070s (Fisher et al., 2012). Likewise, Molua (2009) examined the effects of climate change on the agriculture sector using the Ricardian method. He found that with the change of rainfall by 7 per cent net revenue will decrease by US$2.86 billion while 14 per cent change will reduce US$3.48 billion.

Another important factor which can limit agricultural production is the extreme events. Variation in rainfall and temperature are the basic building blocks of extreme events. Hawkins et al. (2013) conducted an empirical study to find out the effect of droughts on cereal production. They found that droughts can reduce the yield of cereal by 40 per cent in Europe, despite increasing wheat production in recent decades. Zinyengere et al. (2013) conducted a similar type of study to find the effects of climate change on the major cereal crops across Africa. Applying the Ricardian approach they found unequivocal regional disparity of yield reduction. For example, southern Africa, Sub-Saharan Africa, and South Africa will have 18, 22, and 30 per cent yield losses respectively.

Similarly, Bindi and Olesen (2011) investigate the regional distribution of climate impact on agriculture across Europe. They found that Southern Europe experiences largest yield losses due to rain-fed agriculture. While in another country specific study Supit et al. (2010) found country scale cereals yield for several European countries is far below agro-climatic potentials. Some of the studies analyzed the impact of climate change on agricultural production in the context of economic damages. Most of the agronomic studies suggest that under various climate scenarios if the same crop is grown over and again in the same place its yield will reduce. Kurukulasuriya et al. (2006) well illustrate this case. They explain that crop growth will be subject to climate variation which in turn influences crop performance. Angling in a different way, Kurukulasuriya and Mendelsohn (2008) exemplified that warming will reduce net farm revenues. The damages caused by climate change on agricultural productivity will be translated into the reduction of global real GDP.

Correspondingly, Zhai et al. (2009) report that by 2080 global real GDP would decline by 1.4 per cent where India would suffer the largest GDP loss of 6.2 per cent. Likewise, Nordhaus (2008), conducted an empirical investigation to find out the global losses of climate change. The results suggest that with increase in global mean surface temperature by 3^{o}C and associated changes in climate the world would bear a loss of 1.3 per cent of the global economy. Similarly, the total global cost of reducing 50 per cent GHG emissions will be about $200 billion. Considering the losses in global GDP Xiao-Ge et al. (2013) found that global GDP would decline by 1.4 per cent by 2080 as a result of the predicted impacts of climate change on agricultural productivity.

A similar study conducted by Smith et al. (2005) explore the dynamic effects of climate change by analyzing welfare in the long run. They found that the size of the damaging effects of different levels of climate change ranges from 1 per cent to 15 per cent of the GDP with the temperature range of 30°C. However, by traditional Ramsey–Cass–Koopmans specification of the model damages are reported as much as 5 per cent of global GDP.

Some of the studies analyzed the economic cost of climate change. The range of climate effects start from effects on agricultural productivity, energy demand, sea-level rise, human health, to tourism. These studies provide some guidance on how response action should be undertaken keeping in view of the cost of climate change. In this realm, the most prominent and compressive study is conducted by World Bank. According to the World Bank estimates, the cost of climate change adaptation is US$ 9 to 41 billion per year. In this study climate proofing is done by taking a markup factor of current investment flows that are climate sensitive. Further, they assume that 2-10 per cent of Gross Domestic Investment (GDI), 10 per cent of Foreign Direct Investment (FDI), and 40 per cent of Official Development Assistance (ODA) was climate sensitive and that the markup to climate-proof them was 10 to 20.

In a similar study conducted by Stern (2008) there was a reduced markup rate by 5-20 per cent with 20 per cent ODA. They found that adaptation cost worth US$4-US$37 billion. Likewise, Hepburn and Stern (2008) estimated the cost less than US$ 50 billion. This study does include the World Bank's statistics, as well as the cost of community level non-government networks. Congruently, assuming the Stern's 2006 expectation of 17-33 per cent share for climate-sensitive ODA, the United Nation Development Project (UNDP) 2007 estimates the cost of adapting poverty reduction strategies ($44 billion p.a.) and strengthening disaster response systems ($2 billion p.a.). In the same fashion UNFCCC (2007) made five sectors work excluding agriculture, forestry, and fisheries and estimated adaptation cost worth US$49-US$171 billion, where US$28-US$67 billion US$ is for developing countries (Anthoff et al., 2009; Metcalf & Weisbach, 2012; Stavins, 2008).

In the case of climate change, a growing number of studies focused on climate change mitigation policies. For example, (Nordhaus & Boyer, 2000) illustrated this case well. They explain that the role of government is important for regulating fuel economy standards for automobiles, which can reduce CO_2 emission. Such reduction of emission will bring additional monetary benefits for the economy. In doing so the government would need to attach certain value, one such is known as the social cost of carbon (SSC). This value measures the damages associated with emitting a specified quantity of CO_2 emission into the atmosphere. Likewise, Greenstone et al. (2013) noted that the US government used a central estimate of $21 per metric ton for damages associated with CO_2 emission.

Another important study in determining mitigation cost of climate change conducted by Rosen and Guenther (2015). They found that the net cost of mitigating climate change by 2050 is in the range of 1-3 per cent loss of cumulative GDP. The approach used by this analysis appears to be quite wide in range as compared to central values, it also allows growth of GDP as high as 2 per cent under climate mitigation actions. In a similar study, Aldy and Pizer (2009) suggest that emission price would need to be around $40-90 per ton of CO_2 by 2025. Applying meta-analyses Benjamin (2012) estimates marginal damages of $4-20 per ton of CO_2. These estimates have a striking difference with Stern (2007) at $85 and Nordhaus (2007) at $8 per ton of CO_2. The prominent reason for such difference is the selected discount rate assumptions. However, most of the estimates are near-term Pigouvian taxes, which are similar to marginal damage estimates at uncontrolled emissions levels.

Another factor which accounts for the performance of any sector working under climate change conditions is technology. Indeed, the technological change would provide the solution to serious and even persistent environmental issues. Technological change and substitutability are the two most important rationales of making technology an important vehicle for overcoming or at least alleviating environmental problems, including climate change.

Undeniably, the interaction between technical change and environment is now studied from several different angles. Vollebergh and Kemfert (2005) conducted empirical research on the pollution abatement cost of relatively large sectors of the economy. They define this cost as capital expenditure needed to reduce emission to air. They found that the cost is well below 1 per cent of total production cost in many of the industries, which is considered much higher. However, Shadbegian and Gray (2005) argued that the resultant productivity can be distinguished explicitly between traditional output and environmental output to account for what they call the measurement effect.

Considering technical change as an important performance indicator Jones and Williams (1998) found that knowledge spillovers come in a wedge between the social and private rate of return to R&D. Moreover, they found that social return on technical change varies between 30 and 50 per cent. In a similar study Popp et al. (2001) looking at environmental R&D found that private marginal rates of return on investments in physical capital range from 7 per cent to 15 per cent. From the perspective of addressing climate change, the inherent linkage between technical development and redressing climate damages is no longer an academic exercise. Stern (2006) argued that CO_2 emission can be stabilized at 550ppm for an estimated cost equivalent to 1 per cent of global GDP. He included a national confidence interval of 4 per cent losses with 2 per cent gain.

Similarly, in a widely acknowledged work of Popp (2004) found that technical change increases welfare by 9.4 per cent. With the assumption of zero crowding out welfare, gains are reached to as much as 45.3 per cent. However, with the full crowding out effect gains reduced to 1.9 per cent only. Likewise, in an identical study Nordhaus (2002a) assumes that growth rate of emission intensity is a function of annual R&D directed at carbon saving. He found that additional costs of technical change will bring returns that are 4 per cent higher than ordinary investment costs.

In the parallel step on that journey, Goulder and Mathai (2000) found that knowledge accumulation reduced mitigation costs by 30 per cent. And not surprisingly, the cost can be reduced by 30 per cent with endogenization of technological change. Moreover, Söderholm and Sundqvist (2003) address endogeneity and found that technical change in the form of learning-by-doing contributes 5 per cent in cost reduction, while in the case of learning-by-searching it would by around 15 per cent. A recent summary of (IPCC, 2011) reported similar rates for learning-by-doing rate, while the addition of R&D effects come up with new results. With the doubling of R&D, the cost will change from 1 to 11 per cent point.

Economic theory is relatively clear about the positive long-term consequences of the introduction of new technologies which lead to increased factor productivity. Provided that the supply of production factors is not adversely influenced, higher productivity can be expected to raise potential output. However, gradual climate change has some implication on public finances through several factors e.g. shifts in economic structures, changes in public health expenditure, and costs related to public infrastructure.

Van Der Sluijs et al. (2005) conducted a study by combining qualitative-quantitative analysis of climate change impacts on several sectors. They estimate direct and indirect effects of climate change on government finance. Their analysis found that climate change could result in decreasing revenue, while expenditure will increase. This, in turn, has a negative impact on government expenditure and equal to as much as 0.6 to 2.5 per cent of GDP losses. In a similar study, Heipertz and Nickel (2008) found that direct and indirect monetary impacts of extreme weather events on public finances were between 0.3–1.1 per cent of GDP. Using panel data of 138 countries Heipertz and Nickel (2008) estimate the fiscal impact of extreme weather events. They found that extreme weather events can cause negative impacts government expenditure, which in turn increase it by 0.23–1.1 per cent of GDP depending on the country vulnerability. Moreover, analyzing the aftermath of natural disaster Noy and Nualsri (2011) emphasize that fiscal behaviors of developed countries are counter-cyclic, while for developing countries it will be pro-cyclic. In studying monetary effects of climate shocks Melecky and Raddatz (2011) found that government expenditure escalates, while budget deficits worsen after climate shocks in high and middle-income countries.

In the same way, we assess the socio-economic impacts of climate change on private consumption will be negative. From the socio-economic point of view, changes in the climate directly affect consumption of livelihoods through their impacts on production (agricultural and non-agricultural) and income. Indirectly, climate changes affect the prevalence of diseases or the level of the risk associated with the exposure to non-trivial weather changes that cause health-related effects.

The direct or indirect interplay between climate change on one hand and private consumption on the other eventually determine the final welfare impact of climate change. Various climate impact studies show that changes in weather conditions will directly reduce the production of most vulnerable sectors like agriculture and fisheries (Rabassa et al., 2014; Skoufias et al., 2010). In this context, Albouy (2009) estimated the welfare impact of climate change on household consumption. They found that climate change can decrease the private consumption by 2 to 3 per cent of GDP. The reduction in consumption is attached with a reduction in private income.

Despite the negative impacts of climate change, numerous studies have depicted a significant positive relationship between climate change and agricultural production (Lobell et al., 2008; Parry et al., 2004). These studies have highlighted that by small changes in temperature agricultural productivity will increase in temperate zones (Maracchi et al., 2005). Until now, most of the literature discussed arises mostly from developed countries. Since the focus of the study is Pakistan, a South Asian developing country, it is essential to analyze the studies conducted in South Asia in this respects. The following section exclusively focuses on this.

2.11 Evidence from South Asia

South Asia comprises of eight countries i.e., Afghanistan, Bangladesh, Bhutan, India, the Maldives, Nepal, Pakistan, and Sri Lanka. It is home to over one-fifth of the world’s population. It is also important to note that, higher population growth rate coupled with natural resource degradation make South Asia one of the most disaster-prone regions in the world (UNEP, United Nations Environment Programme 2003). Among studies conducted on climate change and the performance of the agricultural sector in South Asian countries, most of the studies focused on India, Bangladesh, and Pakistan, mainly due to higher agricultural contribution to their economies.

To begin with, in the case of India Annamalai et al. (2007) expounded that, a strong linear relationship exists between wheat yield and temperature increase. For example, they claim that every degree increase in the mean temperature would decrease grain yield by 428 kg/ha. Likewise, Panda (2009) carried out an empirical study to find the linkage between the climate change and agricultural vulnerabilities. He uses the Ricardian approach, and took net revenue as a dependent variable, with temperature and precipitation changes as independent. His study concluded that rise in mean temperature by 20°C and 7 per cent increase in mean precipitation will decrease net agricultural revenue by 12.3 per cent.

Similarly, Prabhjyot-Kaur (2007) undertook a study to find the extent of productivity decline of rice by an increase in minimum temperature. They found that a temperature increase of up to 1-30°C above normal has led to decline in productivity of rice and wheat by 3 per cent and 10 per cent respectively. Menzel et al. (2006) probe the impacts on winter crop. The results are projected to reduce yields up to 7 per cent, 11 per cent and 32 per cent by 2020, 2050, and 2080 respectively in India. Considering losses in GDP Zhai and Zhuang (2009) found that with the decrease in agricultural productivity by 24 per cent GDP may decrease up to 6.2 per cent.

Concentrating on an improved level of management with climate change Geethalakshmi et al. (2011) administrated a study on rice yield performance. They found that 1°C increase in temperature with zero increase in CO_2 emission results in 5, 8, 5 and 7 per cent decrease in grain yield in north, west, east and southern regions, respectively. However, with an increase of 2°C temperature yield reduction would be 10-16 per cent in different regions, whereas a 4°C rise led to 21-30 per cent reduction.

In a similar study in Bangladesh, Islam et al. (2008) found that a maximum increase of temperature by 1° C rice production would decrease by 17.28 tons. Moreover, increase in temperature by 2 to 4°C would impair wheat and potato growth, and production losses may escalate from 60 per cent with such high temperature. Focusing on the sea level rise, OECD conducted a study in Bangladesh, the estimated losses to GDP range from 28 to 57 per cent due to a 1m rise in sea level.

From the perspective of vulnerability, Pakistan is ranked 2nd globally. The anticipated economic losses due to climate change are approximately US$ 4 to 5 billion, where productivity of grassland, crop, and livestock are expected to suffer severely. Babar and Amin (2014) conducted an empirical study to find the effect of increased temperature and rainfall on Rabi and Kharif crops. They found that Rabi crops yield decreased from 1565 Kg/hectare to 1520 Kg/hectare, where Kharif crop shrinks from 1880 Kg/hectare to 1783 kg/hectare. In a similar study, Shakoor et al. (2011) empirically analyze the impact of temperature and rainfall on crop productivity of Pakistan. They applied the Ricardian method to check the net revenue. The results show that 1°C increase in temperature will produce a loss of 4180 rupees, and with the increase in temperature losses goes on to increase. However, they found a positive impact of rainfall on net revenue. With the increase of rainfall around 8 per cent net revenue increased by 377 rupees.

Angling in another way, Ghalib et al. (2013) highlighted the impact of climate change in terms of reduced water availability, which can reduce per hectare output of the crops. They use the regional climate change model, and predict that southern Pakistan will experience 15-20 per cent reduction in wheat yield; however, minor improvement in yield can be found in northern Pakistan. Moreover, plant disease, pest, and weed attacks will increase while the forestry and fishery industries will be negatively affected.

The South Asian region is already food insecure, and climate change poses a serious threat to future crop productivity. Benjamin (2012) assessed the projected impact of climate change on 8 major crops of South Asia. They conducted a meta-analysis of data and found that the mean yield of all the crop will decrease by 8 per cent by the middle of the century. However, yield change for maize is 16 per cent, and for sorghum 11 per cent. The result clearly indicates that climate change has serious implication for farming livelihoods of the poor, where agricultural knowledge and technology is orthodox. In a similar study from World Bank (2009), 75 per cent of poor are rain-fed agriculture dependent and climate change is worsening their livelihood badly.

Moreover, climate change effects on agriculture vary according to location. However, the model projected a range of 15 to 30 per cent decrease in the productivity of most cereals in South Asia. Additionally, by the mid-21st century crop yields are expected to decrease up to 30 per cent. The most drastic impacts are expected in the flood affected and arid zones, where agriculture is already at the edge of climate tolerance limits. In a condensed form, one thing is common among all the studies discussed above the agricultural sector is on the edge of its tolerance limit. Likewise, lack of technology and modern agricultural practice knowledge further hampers crop productivity and agricultural growth. Under such circumstances climate change affects the entire agriculture system from changing the ecosystem to the market price and quantity of agricultural output.

2.12 Integrated Assessment Models and Agricultural Damages

In the early 1990's IPCC, has focused mainly on the physics of climate change, instead of its socio-economic dimensions. The focus changed with the adoption of Integrated Assessment Models (IAMs) of climate change, which examine the key interactions between society and climate system by combining natural and social scientific information. In climate change literature, IAMs reflect a range of modelling approaches to translate climate impacts into monetary damages (for example calculation of the social cost of carbon)[8] and policy relevant information. The policy relevant information is divided into two categories i.e. policy optimization and policy evaluation (Goodess et al., 2003).

Considering monetary translation of climate damages Nordhaus (1993) estimated the damages to the US economy as a result of 3°C of warming using the Dynamic Integrated Climate and Economy (DICE) model. Based on the results initial damages were reported as 0.25 per cent of GDP; however, later estimates are raised to 1 per cent, while for global damages the figure was 1.33 per cent. Moreover, with the passage of time improvements in the damage estimation have been done in the DICE model. For example Cline (1996), Nordhaus (1993), Fankhauser (1994), and Titus (1992) produce estimates of 1, 1.3, 2.5, and 1.5 per cent of global GDP damages respectively. Although

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[8] Monetary estimates of the benefit of cutting one ton of carbon emissions today.

all these first generation models have done an admirable job, they were not widely acknowledged because of their simplicity, assessment of damages was done on non-benchmark climate change, and the model do not yield insights into the sensitivity to climate change of future societies. Therefore, Tol (1996) classify damage dynamics using the Climate Framework for Uncertainty Negotiation and Distribution (FUND) model and found that the estimated global monetary damages would be 2.8 per cent of GDP.

Considering the regional significance of climate change the Regional Integrated model of Climate and the Economy (RICE) model, segregated the world into a number of regions. Each region is endowed with some initial capital stock and population. The results of the model show that the US would experience consumption losses of US$12 billion through 2050, while the rest of the world (ROW) regions would suffer major losses approaching a total of US$100 billion by mid-century. Additionally, combining the numbers of the different regions, the negative impact of cumulative global consumption still prevails.

The Stern's review paves the way for the debate about climate economics. Due to its innovative approach Stern (2006) estimates the damages that would be expected under business-as-usual conditions by using the Policy Analysis for the Greenhouse Effect (PAGE) 2002 model. The estimated results show that under the narrow definition of climate damages, global welfare costs would be 5 per cent, while under the broadest definition it piles up to as much as 20 per cent of GDP by the end of this century. However, these estimates were sustainably greater than early estimates (Kurukulasuriya et al., 2006; Tol & Yohe, 2006).

In the case of policy-relevant models, policy optimization models are designed to minimize mitigation costs and monetize damages from climate impacts. These models have limited numerical complexities, by representing climate and economic systems by a small number of equations. The main applications of such models are cost-benefit analysis or social welfare, generally expressed in terms of maximizing economic wealth. Policy optimizing models are subject to constraints, such as avoiding the specific level of temperature increase. The main example of such models includes DICE/RICE (Nordhaus, 2014), FUND (Tol, 2005), PAGE (Hope, 2006; Hope, 2009), and Model for Evaluating the Regional and Global Effects of GHG Reduction Policies (MERGE) (Manne et al., 1995).

Similarly, to calculate the consequences of specific climate policy strategies in terms of suitability to environmental, economic, and social performance measures policy evaluation models are designed and used. When such models are subjected to constraints of optimization models, they engender complexities of natural and social processes representations. The application of such models generally focused on the comparison of consequences of alternative scenarios. The most common examples of such models are Asia-Pacific Integrated Model (AIM) (Fujino et al., 2006), Model for Energy Supply Strategy Alternatives and their General Environmental Impact (MESSAGE) (Messner & Strubegger, 1995), Integrated Model to Assess the Global Environment (IMAGE) (Alcamo et al., 1998) , and the new Community Integrated Assessment System (CIAS) (Warren et al., 2008). It is also important to note that policy optimization models (e.g., DICE/RICE, FUND, and PAGE) can be applied for evaluation purposes, but their algebraic simplicity limits the range of questions they can address.

2.13 Summary

This chapter begins with the discussion on the definition and dimensions of climate change. It further extends to the physical and economic impacts of climate change on agricultural production. It also explains the response actions of climate change and their limitations for analyzing agricultural economies. This chapter, taking a different angle, necessitates the need of technical change in redressing climate damages in a developing county case. Moreover, it elabourates the methodologies used to gauge climate change effects on agricultural production and their issues. This chapter concludes that a comprehensive measure is needed to scale the climate effects on agriculture that can encapsulate the various dimensions of climate change. The empirical and theoretical literature review appears to support the notion. In condensed form, the literature review identifies three major points. First, it highlights the importance of examining the effects of climate change on agriculture. Second, it illustrates the need for another response action besides adaptation and mitigation, taking into account of the developing country case. Third, it emphasizes for an examination of climate change effects on individual sectors of the economy, using a more comprehensive tool that is able to capture all dimensions of climate change and the sectors in question.

CHAPTER 3: CLIMATE CHANGE AND AGRICULTURAL PRODUCTION IN PAKISTAN

3.1 Introduction

This chapter profiles the climate change perspective of Pakistan as well as the anticipated future climate catastrophes and trends in agricultural production. The first part of the chapter produces a snapshot of climate change in Pakistan. It provides the projected future change in the climate of Pakistan and its associated impacts on the agricultural sector of Pakistan. The next section describes the impacts of climate change on sub-sectors of agriculture, explaining the heterogeneous nature of climate damages across all sub-sectors of Pakistan agriculture. The last section of the chapter summarizes the key points.

3.2 Climate Change and Pakistan

The effects of climate change do not merely involve environmental issues, rather it affects economic growth and human well-being (Nunes et al., 2007). Pakistan lies in the temperate zone with an arid climate in general, characterized by hot summer and cold winter, and wide variation of extreme temperature. These generalizations should not, however, obscure the distinct differences existing among particular locations. For example, the coastal area along the Arabian Sea is usually warm, whereas Karakoram Range is cold year round (Farooqi et al., 2005). Pakistan has four seasons: a cool, dry winter from December through February; a hot, dry spring from March through May; the summer rainy season, or southwest monsoon period, from June through September; and the retreating monsoon period of October and November. The seasonal variations in Pakistan are quite noticeable; however, the onset and duration of seasons vary according to location (Bastiaanssen & Ali, 2003).

Being part of South Asia, known to be the most disaster-prone region in the world, Pakistan is considered most susceptible to natural disasters. The temperature projections for South Asia for the twenty-first century suggest a significant acceleration of warming over that observed in the twentieth century (IPCC, 2007). Pakistan experiences some of the hottest and driest conditions in the South Asia region. According to the Climatic Research Unit (CRU), the temperature trends for the country over the past century do not display a consistent regional pattern yet the country shows an overall increase of 0.6°C over the past century (Griffiths et al., 2005).

According to the Global Change Impact Studies Centre (GCISC) projections, the temperature is expected to rise by about 2°C in northern Pakistan, 1.5°C in central parts of the country and 1°C in coastal areas by 2020s. Additionally, the rate and nature of this change vary over time and across the country. For example, temperature increases over northern Pakistan are 0.8°C, while southern Pakistan reported 0.6°C. These projections indicate alarming trends of temperature changes in Pakistan (Prabhakar & Shaw, 2008; Ul Islam et al., 2009).

With the change in temperature, other climate parameters also display variations. One of the most important parameters is the annual rainfall that shows noticeable disparities. Moreover, relative humidity decreased by 5 per cent and solar radiation increased by 0.5 to 0.7 per cent over the southern part of the country. Sunshine hours increase due to decreases in cloud cover 3-5 per cent in central Pakistan, which increases the net irrigation water requirements by 5 per cent (Farooqi et al., 2005). In similar fashion, extreme weather events have also become worse in Pakistan. The worst drought in the history was faced by the country at the turn of the century. On the contrary, the first decade of the 21st century saw the worst floods in history in 2010. These floods resulted from extremely high rain intensity that reached 300 mm causing water levels to reach their highest in 110 years in the Indus River. The unprecedented floods affected more than 20 million people in 2010 according to the estimates of Refugee International. Similarly, floods in 2011 destroyed nearly 2.2 million ha of cropland; 72 per cent of crops were lost and 1.6 million homes were destroyed. On the contrary, 2007 witnessed a record heat wave that gripped Pakistan and the temperature reached 48°C (Mirza, 2011).

Despite contributing very little to global greenhouse gas emissions, Pakistan is one of the most vulnerable countries to climate change. On the vulnerability index[9] Pakistan ranks 16th among 170 countries. However, before 2010 it was ranked 29th. Table 3-1 provide the empirical evidence of Pakistan movement on climate risk index, it provide its ranking and the estimated losses in GDP from 2010 to 2017.

Table 3-1 Climate Risk Index and Pakistan Economic losses

Years	CRI (Score)	Death Toll	Total losses (Million US$ PPP)	Losses per unit GDP in %
2017	30.50	504.75	3 823.17	0.64
2016	31.17	487.40	3 931.40	0.70
2015	31.50	456.95	3988.92	0.77
2014	12.67	662	6087.82	1.11
2013	30.50	545.9	2,183	0.73
2012	30.67	558	1,834	0.66
2011	60,50	112	1,38	0.02
2010	40.67	480.84	419.41	0.17

Source: UNFCCC Parties

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[9] Maplecroft's (2011) Index of vulnerability.

The sharp movement of the country on vulnerability horizon indicates the augmentation in the susceptibility of Pakistan to climate change. The rationale for the growth in the vulnerability of Pakistan is its warmer climate, the preponderance of arid and semi-arid lands, and dependence of its rivers on the Hindukush-Karakoram-Himalayan glaciers, which are reported to be receding due to global warming (Polsky et al., 2007).

Economically, climate change has widespread detrimental impacts on water, food, and energy security conditions of Pakistan (Iqbal et al., 2011). For example, it causes turbulence in the social dimensions by enhancing the frequency of extreme natural events such as floods and droughts. It could jeopardize hundreds of jobs, may result in inflation of food prices and increase the number of people at risk of food insecurity and hunger. In addition, it could have serious implications for ecology, quantity and quality of land, soil, water resources and water salinity (Martínez-Zarzoso & Maruotti, 2011) which can impair the core sector of the economy like agriculture. However, the relationships between climate change and agriculture are complex and manifold. They involve climatic and environmental aspects, social and economic responses. It is further complicated as interdependencies of climate change and agriculture evolves dynamically over time. Moreover, the time span is often large and surrounded by multiple uncertainties.

Pakistan is a country with an inherited agricultural base. Given the previous few decades climate developments has become a great challenge for the agriculture sector of Pakistan. Analyzing Pakistan's economy, it can be seen that agriculture is the backbone of the economy as it contributes 21 per cent to the GDP of the country. Almost 67 per cent of the population is involved directly or indirectly with agriculture (GoP, 2012). The livelihood of these farming communities depends on agriculture but it is characterized as a relatively risky business. Therefore, it affects the interests of farming communities. The major risks in agriculture caused by different internal and external factors are classified as production, marketing and financial risks, whereas the major reasons for low productivity and reliability of farm income include the non-availability of improved seeds, fertilizers used, weed infestation, shortage of irrigation water, drought and seasonal variation of rainfall, inadequate research efforts and inefficient extension services with respect to many agricultural crops (Mall et al., 2006).

Pakistan is an agriculturally-based country but it is on decline and farmers' inclination towards agriculture is not the same as it was a decade ago. Climate change has potential impacts on agriculture but the farming community is not even aware of it. They don't know that cropping patterns may face drastic changes in the coming 20-30 years because of rising temperatures. We could see a 30 per cent loss of production due to climate change, on top of that traditional methods of agricultural production are still practiced all over the country (Javed, 2010).

The effects of global climate change in Pakistan are already evident in the form of growing frequency of droughts and flooding, increasingly erratic weather behavior, changes in agricultural patterns, reduction in freshwater supply and the loss of biodiversity. Presently Pakistan is conferring little attention in planning for potential climate change impacts on both individual and community levels. Rigorous analysis of the net impacts of climate change on agriculture is yet to be performed on account of the uncertainty associated with the success of any action to handle climate change. Generally, farmers cope with weather patterns on a short term basis and sometimes are able to adjust to potential risks and weather variability through best management practices, but climate change may pose new unpredictable risks for the future of Pakistan similar to rest of the world (Nasim et al., 2012). Therefore, it is important to analyze the impacts of climate change on the agricultural production of Pakistan, as it has multiple dimensions that would result in a decline in productivity and increase the price of many important agricultural crops. Additionally, an invasive inspection of the entire agriculture sector must grasp the idea of downstream sectors’ vulnerability.

3.3 Climate Change and Agricultural Production of Pakistan

The foremost objective of the agricultural sector in Pakistan is to ensure adequate production and availability of food. By virtue of its geographical condition Pakistan has diverse agro-climatic conditions with a good natural resource base (land and water). The contiguous irrigation network of Pakistan provides diversification and intensification of the agricultural production system. Most of the agricultural production contribution comes from crops and livestock, although horticulture is also increasing in importance. On top of that, it needs to provide livelihoods to people directly involved in the sector along with the value adding chain.

In the last three decades of the 20th century, Pakistan witnessed an unprecedented transformation of agricultural production. The transformation started with the advent of the green revolution, supported by input subsidies, investment in agriculture infrastructure, and better policy environment. Hence, it became an agricultural system that was able to increase its agricultural exports, reduce poverty, increase income levels, and improve the quality of life for its people (Gollin et al., 2005). Despite an impressive performance, it has not resulted in improving the living standards of the rural population to the extent desired.

Meanwhile, several challenges have now emerged in a more intense form and need to be addressed. These include increasing water scarcity, degradation of land resources (water logging and salinity), inefficient use of agricultural inputs, ineffective transfer of technology to the farmers, lack of coordination between research and extension, postharvest losses, and marketing infrastructure. Above all the recent developments in climate dynamics create major threats to the agricultural production of Pakistan.

Climate change has a serious threat for all the downstream agricultural sectors of Pakistan. Although all the sub-sectors are vulnerable to some degree, yet the effects are not homogenously distributed. Some of the sectors are highly vulnerable while some have some sort of resistance to climate changes. As a consequence of global warming, average temperature increase has deteriorating effects on crops production of Pakistan (Schlenker & Roberts, 2009). According to researchers like Kurukulasuriya and Mendelsohn (2007) and Seo et al. (2009) geographical location and adaptive capacity of countries shape a number of climate damages to crops output. Therefore, Pakistan's crop sector is extremely vulnerable to catastrophic climate damages. According to FAO statistics, the average yield of Pakistan major crops[10] is currently lower than the global average. Moreover, the production of these crops is sensitive to temperature, hence, most of the crops are witnessing serious productivity gaps. It is also evident from the study conducted by Burton and Lim (2005) that agricultural activity took place closer to heat tolerance is most likely to be negatively affected by climate change.

In fact, Pakistan lies among the twelve most climate exposed countries according to World Bank. Moreover, the reliance of the agricultural sector on climate makes it one of the most highly climate affected among South Asian countries. According to the study conducted by Luers et al. (2003) major agricultural crops of Pakistan are particularly vulnerable to climate change because changes in the weather pattern will affect cropping system and productivity of crops. The temperature increase, uncertain rainfall, and

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[10] Wheat, Cotton, Rice, Maize, and Sugarcane.

droughts caused unexpected production losses for the crop. As agriculture is the lifeline of the country's economy, the influence of changing temperatures is expected to be most lethal in this sector. Moreover, high rates of fertilizer and pesticide use may not translate into corresponding expected increases in yield, due to erratic and sometimes non-optimal applications, which may cause negative environmental impacts.

Food Security of the country has been at risk due to the reduction in annual crop yields caused by various factors like water logging, desertification of land, growing frequency of pest attacks and disasters. Nasim (2010) provides some awful production projections for staple and cash crops of Pakistan under changing climate conditions. According to his findings, 1°C rise in temperature can cause 6-9 per cent decline in wheat yield while the even lesser rise in temperature will severely impact cash crops like mango and cotton. Moreover, climate change effects on agriculture are attached with water availability as Pakistan relies on irrigation for more than 90 per cent of its agricultural production. Considering that only 40 per cent of water diverted from rivers actually reaches the crop, affecting irrigation efficiency is a result of water shortage. Projections for future water availability scenarios are mixed; on the one hand reports by the Intergovernmental Panel on Climate Change (IPCC) suggests that Pakistan will receive a higher level of rainfall with the increasing temperatures, meaning that we will get more water. However, storms and floods resulting from the increase in precipitation coupled with the irregularity of water distribution will most probably offset production benefits of receiving more rainfall (Ashiq et al., 2010; Ul Islam et al., 2009).

Besides the crops, other sub-sectors of agriculture are livestock and fisheries that contribute nearly 50 per cent of the agricultural value added and 11 per cent to the GDP. Collectively, livestock and fisheries contribute 8.5 per cent of total exports. Historically, both the sectors have been subsistence and dominated by small and landless farmers to meet their needs for food, and some cash income. Globally, Pakistan is the world's 5th largest milk producer; its value exceeds the combined value of its two major crops (wheat and cotton). However, average milk yield is 5 liters/day, which is only a fraction of the world average (Amin et al., 2010) . Although major initiatives have been launched to improve animal breeds and milk collections, the white revolution is waiting to happen. The development constraints of these sectors are also multiple e.g. inadequate and poor quality of feed, poor health coverage, inferior livestock, outdated and limited marketing facilities, and lack of investment in R&D and market infrastructure.

In congruence with crops, the livestock sector is also threatened by anticipated climate change. According to Thornton et al. (2009), climate change may have substantial effects on the global livestock sector in various ways, which cause inevitable changes in productivity. For example, heat waves, which are projected to increase under climate change could directly threaten livestock. For example, heat stress can increase vulnerability to disease, reduce fertility, and reduce milk production. Similarly, drought may threaten pasture and feed supplies. Drought reduces the amount of quality forage available to grazing livestock. Additionally, for animals that rely on grain, changes in crop production due to drought could also become a problem.

Climate variability will have severely deleterious impacts on livestock production as well as it reduces the ability of farmers to manage these climate risks. In this way, climate change sabotages the substantial role of livestock in the economy of Pakistan. The economy of Pakistan is dependent on agriculture in many ways. The dependency of our industrial sector on agricultural raw material indicates that climate change is set to harm the supply chain of the industry as well. Consequently, damage to livelihoods will not remain confined to the agricultural sector alone but will also spill over to the industrial markets (Iglesias et al., 1996; Shakoor et al., 2011).

To conclude, the agricultural sector is highly dependent on specific climate conditions. Expounding overall effect of climate change on food supply can be difficult because, on one hand, higher temperature and CO_2 can be beneficial for some crops in some places. On the other hand, such changes in temperature and CO_2 can produce havoc for the same crops or others placed within the same country. Because the benefits of climate change are linked to various other factors like, nutrient levels, soil moisture, water availability changes in the frequency and severity of droughts and floods could pose challenges for farmers and ranchers. Meanwhile, warmer water temperatures are likely to cause the habitat ranges of many fish and shellfish species to shift, which could disrupt the ecosystem. Overall, climate change could make it more difficult to grow crops, raise animals, and catch fish in the same ways and same places as we have done in the past. The effects of climate change also need to be considered along with other evolving factors that affect agricultural production, such as changes in farming practices and technology.

3.4 Summary

Pakistan, along with some other developing countries, have been ranked as one of the most at risk because of its vulnerability to climate change and lack of resources to respond. In developing countries, such as Pakistan, climate change poses a serious challenge to social, environmental, and economic development, and lead to migration within and across national borders of Pakistan. The effects of global climate change in Pakistan are already evident in the form of growing frequency of droughts and flooding, increasingly erratic weather behavior, changes in agricultural patterns, reduction in freshwater supply, and the loss of biodiversity. Pakistan’s vulnerability factor is more obvious due to its agro-based economy.

The adverse effects and impacts of climate change on the agricultural sector of Pakistan are severe as Pakistan is considered a predominantly agricultural society. Recent floods have caused severe damages to agricultural produce and have given rise to food inflation. The changes in climate parameters like heat stress reduced the productivity of crops and livestock. Moreover, increased frequency and intensity of extreme climate events such as floods, drought, and cyclones resulting in heavy damages to both crops and livestock. In fact, the industrial sector of Pakistan depends upon the agricultural sector so these climate changes have a direct effect on the entire economy of Pakistan.

CHAPTER 4: METHODOLOGY

4.1 Introduction

This chapter comprises of three distinct parts. The first part of the chapter recapitulates the general equilibrium theory and conceptual framework of the study. Part two explains the modelling method and equation modules. Along with it, this part briefly explicates the pros and cons of the basic Computable General Equilibrium (CGE) model with its underlying assumptions. The final part of the chapter expounds the Social Accounting Matrix (SAM). It highlights the data dimensions and SAM balancing procedures. It also provides SAM market closure conditions and calibration of CGE model.

4.2 General Equilibrium Theory

The original roots of general equilibrium theory date back to the 1870s. The work by French economist Leon Walras (1874) was the pioneering attempt of the competitive market economy general equilibrium modeling. The empirical side of literature related to modelling the whole economy stems from the general equilibrium theory of Walras, where appropriate simultaneous equations are set to describe the interaction among different agents in macroeconomics framework. It should be noted that because Walras general equilibrium system was stated in mathematical form, his contribution in advancements on modern economic theory is very vast.

The modelling and theory of general equilibrium proved to be useful, for understanding economic interactions between markets and agents in complex market economies (Chumacero & Schmidt-Hebbel, 2004). The application of general equilibrium analysis requires basic understanding, how a vast number of individual with separate decisions coordinate productive efforts to generate equilibrium in supply and demand. Furthermore, it describes how this balance leads to efficient allocation of goods and services in the economy. In a general equilibrium, model consumer tends to maximize their utility subjected to budget constraints while producer maximizes profit. Consumer utility maximization leads to demand side specification, while producer profit maximization leads to supply side specification. The price system plays an important role in coordinating and equilibrating the supply and demand; likewise in constant returns to scale case zero profit condition holds for each industry (Shoven, 1992).

A useful graphical way to study it is the Edgeworth box, after F. Edgeworth. Consider an economy that produces only two commodities, x and y, accompanied by two factors of production, (Capital, k and Labour, l). Every individual's choices/preferences are depicted by an indifference map and all individuals are assumed to have identical preferences. The inter-linkages between inputs and outputs can be represented by the production possibility curve (PPC) assuming the fixed volume of capital (k) and labour (l).

Figure 4-1 describes an Edgeworth box diagram which depicts all the different combinations that are possible with the use of existing capital and labour (k and l) to produce the commodities (x and y). Every single point in the Edgeworth box represents a fully employed allocation of the prevailing resources to commodities, x and y.

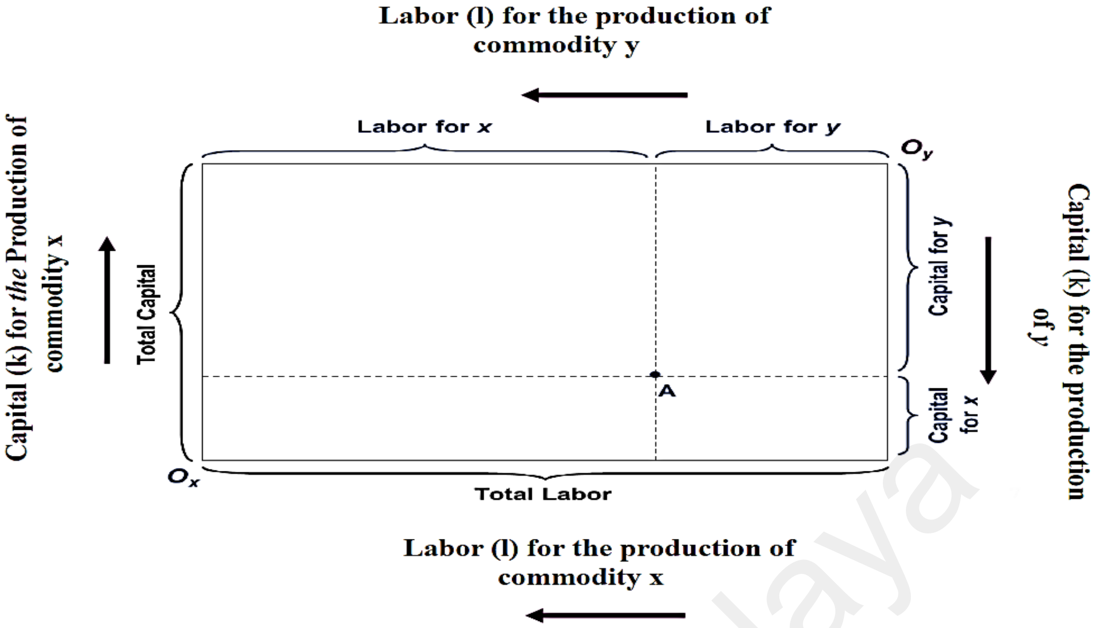

Figure 4-1 Allocation of Available Resources to x and y

From Figure 4-1 it is clear that all allocations in the Edgeworth box cannot be considered efficient technically; many of them are actually inefficient. In fact, by shifting the labour (l) and capital (k) production of either commodity can be increased. To get an efficient allocation, the model uses isoquant maps for the commodities (the isoquant map for commodity x uses O_x as the starting point or origin and the isoquant map for commodity y uses O_y as the starting point or origin) as shown in Figure 4-2.

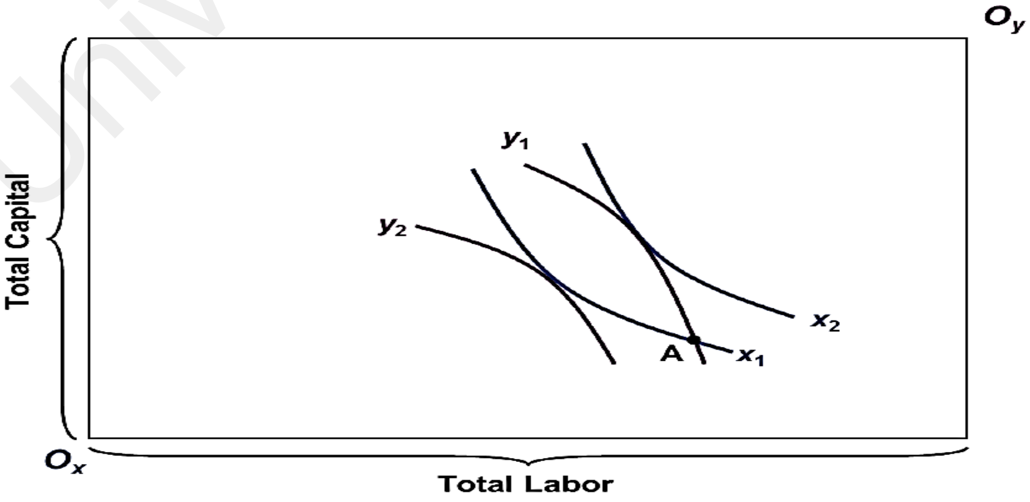

Figure 4-2 Isoquants for Commodities

It shows that the efficient allocations can be found at a point where both isoquants are tangent to each other. Point A is inefficient because, by moving along y_1, productions of commodity x can be increased from x_1 to x_2 while holding y constant or productions of commodity y can be increased from y_1 to y_2 while holding x constant by moving along x_1. Utility maximization requires that marginal rate of substitution of x and y (MRS) should be equivalent to the px/py ratio. Equilibrium position occurs when individuals and firms have the identical price ratio that ensures market clearance ($x^* = y^*$) for all goods together. Similarly, Figure 4-3 shows the locus of all such efficient points that represent the maximum level of output for commodity y that can be produced for an arbitrary level of output for commodity x. Each efficient point of production becomes a point on the production possibility frontier.

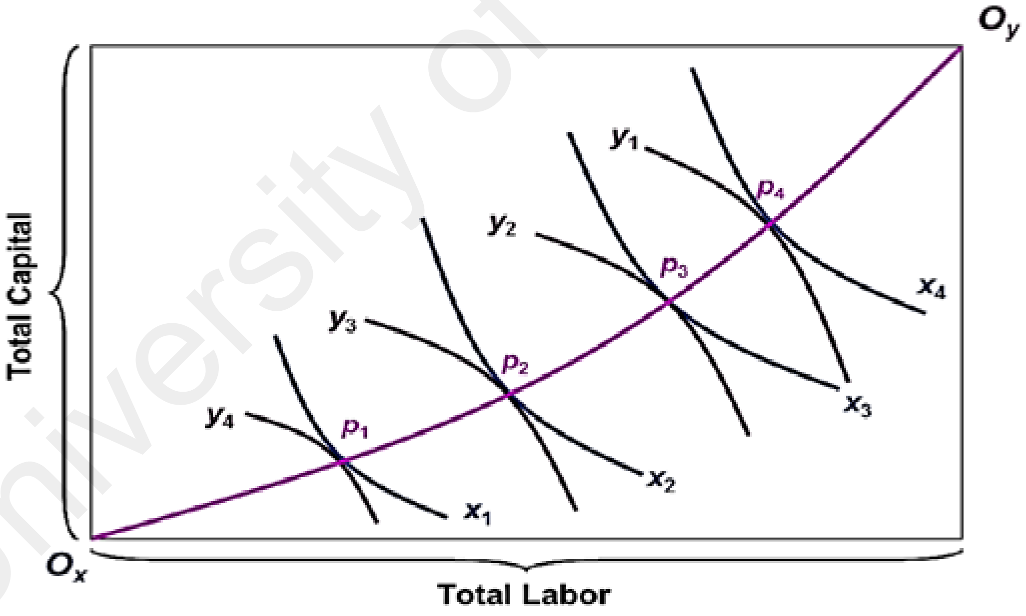

Figure 4-3 Efficient Point Path of General Equilibrium

As a matter of fact, the theoretical general equilibrium structure is formalized by Arrow and Debreu (1954) with realistic economic data in an applied general equilibrium model called Computable general equilibrium (CGE) model (Borges, 1986). In light of Walrasian general equilibrium, Computable general equilibrium (CGE) models are considered as modern Walras model for the competitive economy. However, CGE models are a numerical model that are specifically based on general equilibrium theory (Gilbert & Wahl, 2002). CGE models solve the data numerically to obtain the level of supply, demand, and price that support equilibrium across a specified set of markets. The model incorporates elements of other modelling traditions, for example, Leontief input-output analysis and is considered as a standard tool of empirical analysis.

4.2.1 Neoclassical Economic Growth Theory (Hicks's Assumption)

The economics of climate change and agriculture can be analyzed from the perspective of neoclassical economic growth theory (Nordhaus, 1994). As in the neo-classical growth theory, economies make investments in capital, technologies, health, thereby limiting current consumption in order to increase consumption in future. As per Nordhaus (1994) theory, climate systems act as "Natural Capital", which constitute an additional kind of capital stock. In other words, anthropogenic or natural activities altering natural capital stock which has harmful effects on agriculture production system. To put it another way, we can view climate change as negative natural capital.

Technical change determines the relationship between economic growth and environment (Jaffe et al., 2005). Particularly, in neo-classical growth theory exogenous technical change determines long-run growth. Exogenous technical change has been specified as two distinct functions of time. One follows autonomous energy-efficiency improvement (AEEI) (Nordhaus, 1994). The other captures the overall progress of the economy, typically representing a Hicks-neutral productivity gain based on Hicks's theory. This study considers Hicks's neutral technical change to represent the overall productivity gain, which requires monetary investments up to the optimal level of technical change by the government policymaker's i.e. Pakistan's government as our study focus is on Pakistan. However, there are some certain assumption that must be consider before implementing Hick's neutral technical change. Some of the assumptions[11] are listed below:

1. Marginal Rate of Substitution between each pair of inputs be independent of technical change.
2. Each firm is assumed to be in a position of "internal equilibrium".
3. The firm must expand on its respective expansion path, given its rate of output and minimum cost.
4. Production function must remain input homothetic.
5. Technical change is independent of the factor price ration in the long run.

From the above discussion, the crowning point of the theories is that climate change is significantly important to determine agricultural production (Mendelsohn & Dinar, 1999; Nordhaus, 1994). However, sustainable agriculture productivity can nullify climate damages. Technical change following Hicks's assumption not only facilitates sustainable productivity but also moderate climate damages.

4.3 Conceptual Framework of the Study

The purpose of this section is to describe the conceptual idea behind agricultural production dependence on weather and economic inputs. Scholastic work shows evidence that climate variability decreases the production of agricultural commodities directing by affecting natural capital and indirectly by pouring harmful effects on economic resources (Benjamin, 2012; McCarl et al., 2008). The further literature argues that technical change shifts the production over time by a uniform upward displacement

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[11] For more details on assumption please see (Blackorby et al. 1976; Greenwood et al. 1997)

of the entire production function. In this backdrop, we draw up an analytical framework, which takes agricultural production on one end and climate change on the other.

Additionally, this framework also takes into account Hicks's assumption of technical change, the role of which we specify as a moderator that have cost and residual damages[12]. Figure 4-4 shows our proposed analytical framework. The study employs an integrated approach that combines the economic and ecological dimensions of the Pakistan economy. The climate parameters include climatic damage, carbon cycle, temperature and rainfall fluctuations, carbon emissions, vulnerability and carbon concentration, which are obtained from DICE model, and downscaled to fit in country specific outcomes, with a regional scope. However, damage can be expressed by the sum of residual damage costs and costs of technical change in monetary term. Considering the climate variability and economic resources for associated damage, the optimum Hicks's technical change level is determined. The cost of damage for this optimum level can be used to find out the policy response i-e whether the policy is cost effective or not.

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[12] The difference between each scenario simulation with baseline scenario produce the residual damages of respective sector. Additionally, Lower residual value provide the evidence of exogenous technological change effectiveness (Jaffe et al.2001).

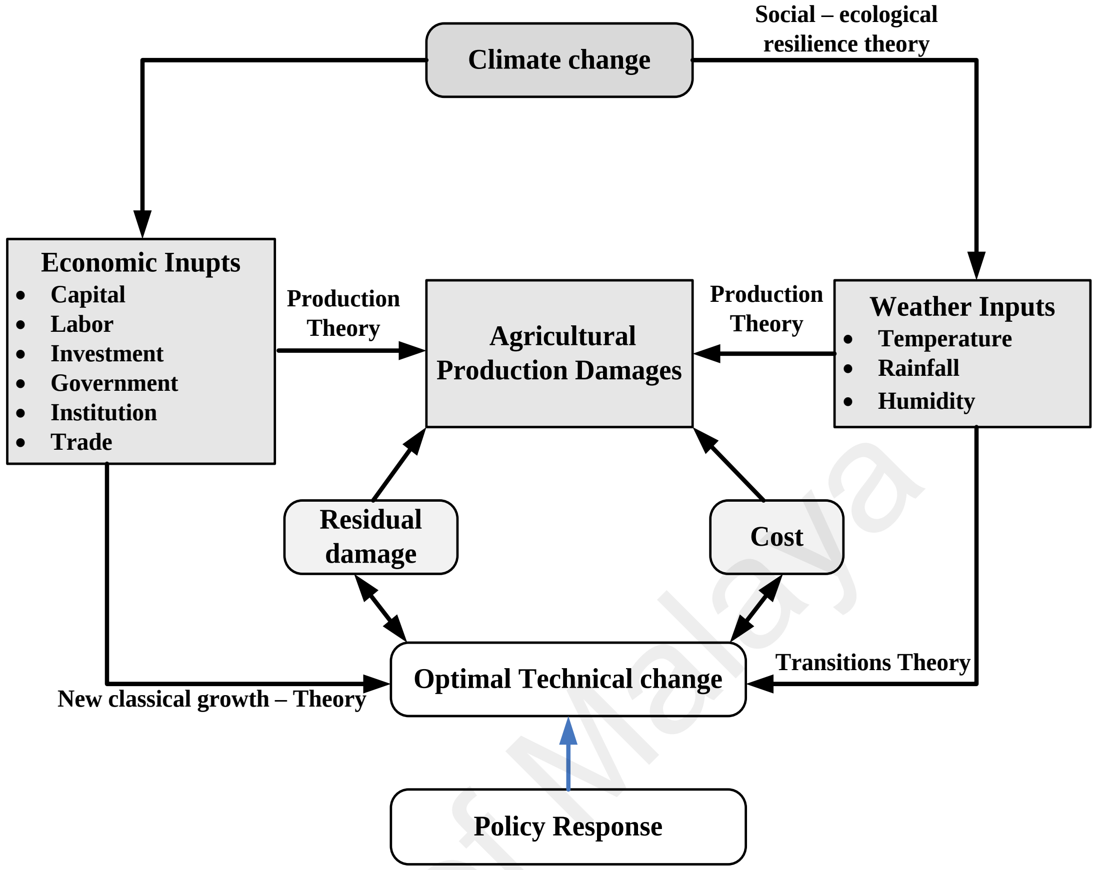

Figure 4-4 Conceptual Framework of the Study

4.4 Modelling Method

In order to achieve the aims of the study, we have used the integrated assessment approach based on the general equilibrium framework. The general equilibrium framework has been chosen for this study because it utilized the Computable General Equilibrium (CGE) model that can represent sectoral and regional scopes policy response efficiently. Hence, it can consider sector, local, regional and global climate damage functions in the most straightforward manner.

4.4.1 Model Overview

The CGE model incorporates the basic features of a well-functioning neo-classical economy. These features include profit and utility maximization, product and factor market clearance, and optimal resource allocation. The CGE model captures all the transactions that are part of the circular flow of income in the economy and it is also variant of trade focused CGE model (Dervis & Robinson, 1982). In this model, the Pakistan economy is aggregated into seventeen sectors. There are two primary factors of production (we aggregated all the factors of production into two-factor labour and capital), three institutional actors (households, government, capital account) and one rest of the world. The systematical view of CGE model is presented in the Figure 4-5 which shows the main real and financial flows, markets, and economic institutions since our main focus is to build a model to capture the effects of climate change on the agricultural sector of the economy.

The agricultural sector is one of the unmanaged and rain-fed sectors of Pakistan economy, which is significantly affected by climate change. Under such conditions integrated assessment is convenient because they combine information from a wide range of disciplines, and attempt to access the causes, impacts, and policy implications of climate change. Basically, these models serve three purposes to deal with the climate issue. Firstly they identify physical, ecological and social processes, the consequences of climate change.

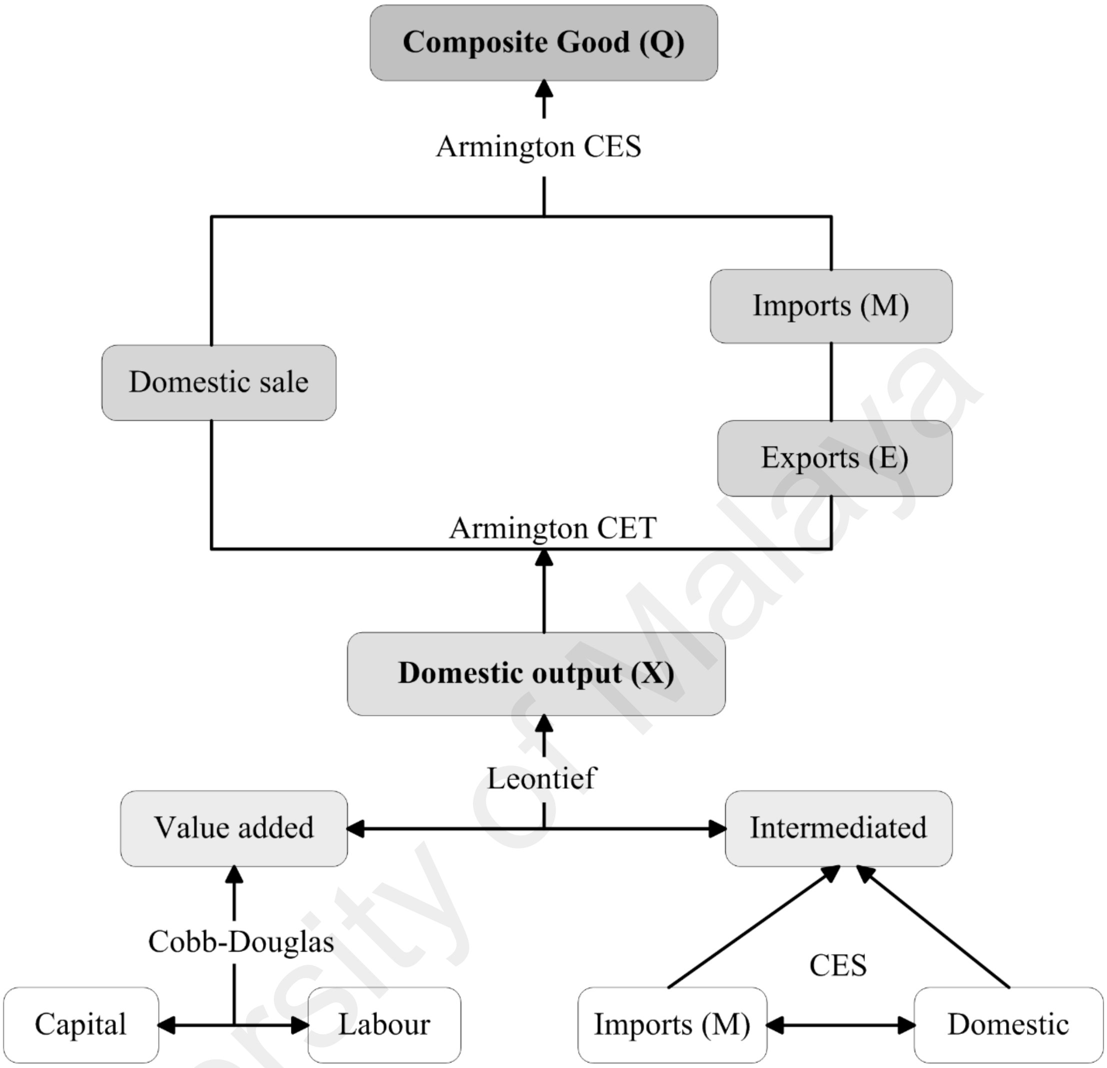

Figure 4-5 Nested Structure of CGE Model and Production Activities

Secondly, they conduct a cost-benefit analysis and finally guide to choose a cost-effective policy response among diverse policy options (IPCC, 2001). As a matter of fact, CGE based integrated assessment approach contains the capability to capture the interaction between economic agents and climate change, which makes it a natural tool for the assessment of climate change. The theoretical formulation in the economic literature allows modification in the CGE model that makes it more competent to completely access the impacts of climate change. Such modifications create bridges between economically oriented frameworks of CGE with physical oriented components of climate change.

4.4.2 Assumptions in the CGE Model

The foundation of general equilibrium models is rooted in the basic assumption of standard micro-economics. The CGE model presented here is based on an estimated Social Accounting Matrix (SAM) for the Pakistan economy for the year 2012. In line with this, few assumptions have been made in this study to align the model with the objective of the study. Furthermore, few modifications in terms of functional form and model's assumptions in the production function technology have been made especially to capture the economy-wide effects of climate change in the economy in general and agricultural sector specifically. The specific assumptions of the CGE model are as follows:

1. The models contain a set of non-linear simultaneous equations having a different degree of order.
2. Producers maximize the profit subject to the "budget constraints while having a constant return to scale, i.e. same proportional change between outputs subsequent to a proportional change in inputs.
3. Producers minimize the costs subject to a production function with the choice between factors governed by a CES in the production function
4. The production technology is organized by a nested structure in a way that elasticity of substitution may vary at the different levels of nesting hierarchy i.e. CES and Leontief Fixed Proportion, are independent of each other
5. Total sectoral output, represented by a CET aggregation of goods and services supplied to the export market (E), and goods sold on the domestic market (D) while composite commodities Qi represent the Armington function differentiated for sectoral imports (M), and domestic good supplied to the domestic market (D).

6. The fundamental equations must satisfy certain restrictions of general equilibrium theory which includes the “Market Clearing Conditions” and “Macroeconomic Closure” process which feeds back into the behavioral equations for demand and supply of commodities and factor market, as well as macroeconomic balances (i.e. Saving-Investment Balance and Balance of Payments) that creates simultaneous equilibrium quantities.
7. Producers maximize profit by taking the equilibrium of input and output prices as given at the supply side while consumers maximize utility subject to their budget constraints defined by their initial factor endowments at the demand side
8. The primary factors of the production (i.e. labour and capital) are assumed to pay the same average wage or rental irrespective of sectors.

4.4.3 Model Structure and Equations

The study goes to adopt an integrated assessment approach to analyze the overall impacts of climate and technical change on the agricultural sector of Pakistan economy. The baseline economy was constructed using Pakistan IO 1990-91 table and 2012 national accounts.[13] The structure and specification of the model follow Löfgren et al. (2001) and Robinson (1989) by aggregating industries into 17 sectors. However, we adopted a multidisciplinary framework by combining an economic and ecological approach to analyzing the costs and benefits of climate damage. The adopted model links climate factors such as climate change, carbon emissions, carbon cycle, and climate damage with the economic variables along the pace of technical change.

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[13] Sector classification is provided in Appendix C.

The equations of the model can be divided into five modules.[14] The first define the price system where second describes the production and total payment to a factor of production. The third is the combination of factor payment to institutional actors and demand system of the institutional actors represented by the institutional module. The climate change module adapted from the DICE model map climate effects. The final module is System Constraints which describes market clearing and macro closure equations of the economy. The following section describes details of all the equations in all modules. For notational convenience, all the parameters are presented in lower cases while variable and indices are presented in upper case letters. All the model variables and parameters are presented in Appendix A and B respectively.

4.5 Price Module

Since Pakistan is a developing country, therefore, it acts as a “price taker” for imports and exports. Likewise, the model incorporates the ‘small country’ assumption, which means the prices of imports and exports are exogenously given whereas, the domestic prices of imports and exports are determined by world prices. The price system of the model is rich, primarily because it assumes quality differences among commodities of different origins and destinations (exports, imports, and domestic outputs used domestically). The price module equations linked endogenous/exogenous price and non-price variables. This section presents the set of price equations used in the model.

4.5.1 Import Price

The price paid by the domestic user for those commodities that enter in the countries in domestic currency unit (DCU) exclusive of sale tax is import price. Since we

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[14] Four modules belong to economic agents adopted from the CGE model, while one is for climate change that is adopted from DICE model.

assume the small country assumption, therefore, import price (pwmc) in foreign currency will be exogenous. Equation 4-1 transforms world import price to domestic import price considering exchange rate and import tariff. This equation applies for only imported commodities where the domain of the equation is the set of imported commodities (a subset of commodity set). The model includes one equation for every imported commodity. The distinction between variables and parameters is made by the notational principles. This also explains that exchange rate and domestic import prices are flexible where tariff and world import prices are fixed[15] (small country assumption).

$$PM_c = pwm_c(1 + tm_c)EXR \qquad \text{4-1}$$

Where

PM_c = Import price in DCU (domestic currency units) including transaction costs

pwm_c = Import price in foreign currency units (FCU)

tm_c = Import tariff rate

EXR = Exchange rate (DCU per FCU)

4.5.2 Export Price

The price received by the domestic producers by selling their product to the international market is called export price (PE) which is also calculated in DCU. Equation 4-2 represents the export price which shows that taxes and traded input cost reduce the price received by domestic producers. The domain of the export price equation is the set of exported commodities, all of which are produced domestically.

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[15] The assumed share of modeled country from world trade is so small that it faces an infinitely elastic supply curve at the prevailing world price.

$$PE_c = pwe_c(1 - te_c)EXR \tag{4-2}$$

Where

PE_c = Export price in DCU

pwe_c = Export price in FCU

te_c = Export tax rate

EXR = Exchange rate (DCU per FCU)

4.5.3 Absorption

The total domestic spending on a commodity at domestic demanded price is known as absorption and represented in Equation 4-3. Absorption is expressed as the sum of spending on domestic output and imports at the demand prices, PD, and PM inclusive of the sales tax. The absorption equation applies to all domestic and imported commodities, while those commodities that are completely exported are not included in the absorption equation.

$$PQ_c * QQ_c = \{(PD_c * QD_c) + (PM_c * QM_c)\} * \{1 + tq_c\} \tag{4-3}$$

Where

QQ_c = Quantity of goods supplied to domestic market (composite supply)

QD_c = Quantity of domestic sale

PD_c = Domestic sale price

tq_c = Sale tax rate (composite price share)

The right-hand side of Equation 4-3 applies only to domestic demand and imports respectively. Likewise, the price and quantity of those commodities that are not part of imports are fixed at zero. In essence, the absorption equation is transferred to market or composite price by multiplying with the sale tax adjustment.[16]

4.5.4 Marketed Output Value

The sum of the values of domestic sale and exports valued at producer price are known as marketed output value as shown in Equation 4-4. It includes domestically produced commodities while excludes the value of output consumed at home. The price received by the suppliers is used to value domestic sales and exports which is further adjusted downwards to accounts for the cost of trade inputs. Since the model includes the category of imported commodities which are not used for domestic production, therefore the domain of domestically produced commodities has to be stated explicitly. Moreover, non-exports commodities should be fixed at zero.

$$PX_c * QX_c = (PD_c * QD_c) + (PE_c * QE_c) \qquad 4\text{-}4$$

Where

PX_c = Aggregated producer price for commodity

PD_c = Domestic sale price

QD_c = Aggregate quantity of domestic output

PE_c = Export price

QE_c = Quantity of export

4.5.5 Activity Price

The return from selling the output is called activity price. However, it can be calculated as the yield per units of activity multiplied by activity specific commodity

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[16] Sales tax adjustment rate is (1+tq) instead of (1-tq) because there is no export tax involved and it adds government revenue.

price, which is further sum across all the commodities. This function allows highlighting the fact that single activity can produce multiple commodities and vice versa. Equation 4-5 represents the activity price which is given as follows:

$$PA_a = \sum_{c \in C} PXAC_{ac} . \theta_{ac} \qquad 4\text{-}5$$

Where:

PA_a = Price of Activity

$PXAC_a$ = Producer Price for Commodity (Aggregate)

θ_{ac} = Yield per unit of activity a

4.5.6 Value Added Price

Value added price is the difference between aggregate intermediate input price and activity revenue/costs. Aggregated activity specific intermediate input price shows cost of disaggregated intermediate inputs per unit of aggregate intermediate input. In general, it depends on the price of the composite commodity and intermediate input coefficients. The intermediate input coefficients show the quantity of input commodity per unit of intermediate input instead of per unit of output. In the case of each activity, it is mandatory to exhaust total revenue net of taxes by payment for value-added and intermediate inputs. Given the activity price and aggregate intermediate input price value added price can be found as shown in the Equation 4-6.

$$PVA_a = PA_a - \sum PQ_c * ica_c \qquad 4\text{-}6$$

Where:

PVA_a = Price of value add

PA_a = Activity price

PQ_c = Composite commodity price

ica_c = Non-exported commodities

4.5.7 Consumer Price Index

The consumer price index is an exogenous variable, which acts as numeraire in domestically marketed output. Since the model is homogeneous of the degree zero in prices, therefore, the numeraire price is mandatory. Similarly, the numeraire price is useful in case we aim to double price while keeping output constant. All the simulated price and income changes should be interpreted as changes vis-a-vis to numeraire price as shown in Equation 4-7.

$$\overline{CPI} = \sum_{c \in C} PQ_c . cwts_c \qquad 4\text{-}7$$

Where:

PQ_c = Price of composite good

$cwts_c$ = Commodity weights in the consumer price index

4.6 Production Module

This module of equation covers four categories: input use and domestic production; allocation of domestic output for home consumption, aggregated domestic market supply, and the demand for trade inputs generated through the distribution process. We also incorporated the technological change in the production function, by comparing pre and post-technological change production outcome. As per model assumption, each sector produces a gross output with constant returns to scale by minimizing cost. The production technology is represented by the constant elasticity of substitution (CES) and represent the nested structure of production hierarchy (Shoven, 1992). This implies that elasticity of substitution may vary at a different level of the nesting hierarchy by remaining independent with each other.

In this model four-tier-nested CES Production structure has been adopted, as shown in Figure 4-5. However, the functional form of fundamental nested CES and Leontief Production Function must satisfy general equilibrium theory restriction (Robinson, 1991). Furthermore, at the top level of the technology nest two alternative specifications are permitted, i.e. the activity level is allowed to be CES or Leontief function of the quantities of value-added and aggregate intermediate input use. The corresponding equations of four categories are explained below:

4.6.1 Production Function

Production function shows the linkage between activity levels which is a CES function of value-added and aggregate intermediate input. However, the optimal mixture of value added and intermediate input is a function of their relative prices. The Equation 4-8 shows the production function used in the model to quantify activity level.

$$QA_a = \sigma_a \prod F_a . QF_f^{\propto f} \qquad 4\text{-}8$$

Where:

QA_a = Level of activity

σ_a = Shift parameter (efficiency parameter)

$F_a . QF_f^{\circ}$ = Capital stock

$\propto f$ = Share parameter

4.6.2 Production Function (Climate and Technical Change)

Technical change can be incorporated in different forms. Broadly it can be distinguished in two groups: neutral and non-neutral technical change. Technical change can influence production function through shift or share parameters. Non-neutral technical change alters the combination of labour and capital as proposed by Solow (1957) and Harrod (1939). However, neutral technical change will cause a shift in production function by changing the efficiency of a factor of production (Hicks, 1963).

In the case of an agricultural-centric model that takes climate change into account, which will definitely reduce total factor productivity, we can apply neutral technical change to overcome the reduction in factor productivity. The production efficiency will increase as a result of Hicks's neutral technical change without any alteration of input combination. Furthermore, it will help to overturn the damages caused by climate change in agricultural production. Therefore, the Equation 4-9 provides the framework through which we can incorporate Hicks's neutral technical change in the model.

$$QAC_a = \left\{ \sigma_a \prod F_a . QF_f^{(\propto f-1)} \right\} * \{1 + \gamma_f\} \qquad 4\text{-}9$$

Where:

QAC_a = Level of activity with climate change

$\sigma_a \prod F_a . QF_f^{(\propto f-1)}$ = Previous year production/activity

γ_f = Hicks's neutral technical change

4.6.3 Gross Output

After calculating the two different level of activities, i.e. with and without technical change we proceed to calculate the gross output produced with the gross climate damages. Equation 4-10 gives the gross output from the aforementioned level of activity in the presence of climate damages.

$$Y_a = GD_t * QA_a \tag{4-10}$$

Where:

Y_a = Gross Output

QA_a = Level of activity

GD_t = Gross Damages

4.6.4 Net Output

Once we obtained two different level of activities and gross output the next step is to calculate net output with climate change. For the calculation of net output with climate change, gross damages are incorporated in the equation with activity level. Therefore, given the activity level and gross damages net output is represented in Equation 4-11.

$$NQ_a = QA_a\{RGDP_t/(1 + GD_t)\}\{1 - ADPC_t/RGDP_t\} \tag{4-11}$$

Where:

QA_a = Level of activity

GD_t = Gross Damages

$RGDP_t$ = Real gross domestic product

$ADPC_t$ = Adaptation cost[17]

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[17] Since we are looking for technological change therefore adaptation cost will be zero in this case.

4.6.5 Factor Demand

As mentioned above each activity demands factor of production. These factors of production value added are basic CES function. The activity demand of factors goes to the point where the marginal cost of each factor equates to marginal revenue. However, marginal revenue product of the factor should be net of intermediate input cost. Equation 4-12 gives factor demand, the domain of the equation is limited to the factor activity combinations that appear in the base-year SAM.

$$WF_f * WFDIST_{fa} = \propto_{fa} * PVA_a\{QA_a/QF_{fa}\} \quad \text{4-12}$$

Where:

$WFDIST_f$ = Factor market distortion parameter

QF_{fa} = Production function share parameter

PVA_a = Value added price

In the model wage-distortion factor is considered as an exogenous variable while average factor price is an endogenous variable. This treatment of factor market basically helps in generating factor market equilibrium (Löfgren et al., 2001).

4.6.6 Intermediate Input Demand

Intermediate demand for each activity is determined via a standard Leontief formulation. Equation 4-13 gives the framework of intermediate input calculation; here a fixed intermediate input coefficient is used along with the level of intermediate input.

$$QINT_{ca} = ica_{ca} * QA_a \quad \text{4-13}$$

Where:

$QINT_{ca}$ = Quantity of commodity c as intermediate input to activity A

ica_{ca} = Quantity of c as intermediate input per unit of activity A

4.6.7 Commodity Production (Output Function)

Commodity production represents production of commodities with a certain level of activity as shown in Equation 4-14. The right-hand side of the equation shows the sum of production quantities, while the left-hand side represents output produced domestically. This equation elabourates two important points, first, one or two activities can produce a single commodity. Second, any activity can produce one or more commodity.

$$QX_c = \sum_{a} \theta_{ac} * QAa \qquad 4\text{-}14$$

Where:

QX_c = Domestic output production

θ_{ac} = Yield of output c per unit of activity ‘a’

4.6.8 Output Transformation (CET) Function

The domestically produced commodities are allocated to two different destinations: domestic sales and exports. Output transformation function is used to split domestic production into two segments by ensuring transformability assumption between the destinations as shown in Equation 4-15. Technically it is similar to CES; however, it has negative substitution elasticity. The lower limit of transformational elasticity is fixed to one. This restriction is made to ensure the concaveness of isoquant corresponding to output transformation function. Mathematically it is presented as follows:

$$QX_c = \alpha_c\{\delta_c . QE_c^{\rho_c} + (1-\delta_c)QD_c^{\rho_c}\}^{1/\rho_c} \qquad 4\text{-}15$$

Where:

α_c = Shift parameter: CET function

δ_c = Share parameter: CET function

ρ_c = Exponent of CET function

4.6.9 Export-Domestic Supply Ratio

In contrast with output transformation function, export domestic supply ratio provides an optimal mix of commodity supply between two destinations i.e. exports and domestic sales. The framework for this optimal mix is given in Equation 4-16.

$$QE_c/QD_c = \left(\frac{PE_c}{PD_c} . \frac{1-\delta_c}{\delta_c}\right)^{1/\rho_c - 1} \qquad 4\text{-}16$$

Given the two prices and fixed quantity of domestic output subjected to CET function Equation 4-4, 1, and 16 constitute the first-order conditions for producer revenues maximization. It is also important to note that Equation 4-16 illustrates the direct relationship between export-domestic supply ratio & export-domestic price ratio. In some of the cases, the output is either used domestically or exported completely, therefore, Equation 4-17 provides the framework of non-exported commodities that are domestically consumed.

$$QX_c = QD_c \qquad 4\text{-}17$$

Where

$c \in CEN$ = Non-exported commodities

4.7 Composite Supply (Armington Function CES)

Composite supply is the mixture of goods that are produced domestically or imported (enter as input in the production process). It is captured by CES aggregation function as shown in Equation 4-18. This function shows the imperfect substitutability between imports and domestically sold output. Imports and domestically produced commodities constitute the domain of the function, the lower limit of the elasticity of substitution is minus one, and therefore, it is often called Armington function.

$$QQ_c = \alpha_c^q . \left\{ \delta_c^q . QM_c^{-\rho_c^q} + \left(1 - \delta_c^q\right) . QD_C^{-\rho_c^q} \right\}^{-1/\rho_c^q} \qquad \text{4-18}$$

Where:

α_c^q = Shift parameter of Armington function

δ_c^q = Share parameter of Armington function

ρ_c^q = Exponent of Armington function

4.7.1 Import-Domestic Demand Ratio

As in the case of export and domestic sale we created an optimal mix. Similarly composite commodity is the optimal mix between imports and domestic output. The domain of this optimal mix is composed of imports and domestic production. Mathematical formulation of the function is given in Equation 4-19.

$$\frac{QM_c}{QD_c} = \left\{ \frac{PD_c}{PM_c} . \frac{\delta_c^q}{1 - \delta_c^q} \right\}^{1/1+\rho_c^q} \qquad \text{4-19}$$

Equation 4-19 also represents the direct relationship between domestic import price ratio and import-domestic demand ratio. Give the two prices and subject to Armington function with a fixed quantity of a composite commodity Equation 4-3, 4-18 and 4-19 constitute the first order condition for cost minimization. Equation 4-20 gives the quantity of the commodity that is produced and sold domestically and there are no imports involved at any stage of production or sale.

$$QX_c = QD_c \qquad 4\text{-}20$$

4.8 Institutional Factor Incomes

The flow of income from value added to the institution and ultimately to households is mapped by the institutional and factor income module. The inter-institutional cell entries in the SAM balanced account framework is basically responding by these equations. The flow of income to the government from all the institutions along with the saving and investment in capital and financial institutions is captured by these equations. It is the combination of three major macro balances i.e. savings-investment balance, the government budget balance, and market balance. In the following section, all the equations representing institutions income and expenditure are explained.

4.8.1 Share of Household in Factor Income

Total income of each factor of production is defined in Equation 4-21. This income is not adjusted for taxes or any transfers. It includes factor market distortion to capture all the income obtained from different markets. This equation shows the sum of all factors of production income in the economy.

$$YF_f = \sum_{a \in A} WF_f . \overline{WFDIST_{fa}} . QF_{fa} \qquad 4\text{-}21$$

Where

YF_f = Total factor income

Share parameter is used to derive household (Institution) income that is further adjusted with direct taxes on the factor of production and transfer payments to the rest of the world (ROW). The latter are fixed in foreign currency and transformed into domestic currency by multiplying with the exchange rate. Equation 4-22 is obtained by applying all the changes in the Equation 4-21. It is also important to note that factor income tax is a value-added tax which is not applied in Pakistan, therefore, it will be zero. Likewise, the factor income transfer to rest of the world is also considered zero.[18]

$$YF_{hf} = shry_{hf}\left\{\left(1 - tf_f\right) * YF_f - tr_{ROW_f} * EXR\right\} \qquad 4\text{-}22$$

Where:

$shry_{hf}$ = Share of household *h* in factor income *f*

tr_{ROW_f} = Transfer of factor income to ROW

tf_f = Value added tax on factor of production

4.8.2 Household Income

Household is one of the subsets of domestic institutions. The total income received by household is the sum of the income received from a factor of production and the transfer payments by other institutions. Equation 4-23 sums up household income from all the sources.

$$YH_f = \sum_{f \in F} YF_{hf} + tr_{hGOV}.CPI + tr_{hROW} * EXR \qquad 4\text{-}23$$

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[18] Since Pakistan is a labour exporting country.

Where:

CPI = Consumer price index (Numeraire)

tr_{hROW} = Transfer of factor income to household from ROW

To make the model homogenous of degree zero government transfers are indexed to CPI. This indexing will not influence the result because CPI acts as the numeraire.

4.8.3 Household Consumption Demand

Household consumption is determined by the level of income, however in this model climate change is an additional factor that can influence consumption. Therefore, we added climate damage as an additional variable to check the effect of climate change on the consumption demand of households. Likewise, to make demand functions explicit we divided the right-hand side of the equation by the composite commodity price PQ. Equation 4-24 shows the consumption demand of households adjusted with climate change damages.

$$QH_{ch} = \frac{\beta_{ch}(1 - MPS) * (1 - ty_h)}{PQ_c} + GD_t \qquad 4\text{-}24$$

Where:

β_{ch} = Consumption spending share of household

PQ_c = Price of composite commodity

MPS = Marginal propensity to save

4.8.4 Investment Demand

Investment demand is the product of base year investment quantity and the adjustment factor. Since adjustment factor is exogenous, therefore, it also makes investment quantity exogenous. In the SAM we aggregated inventory with the saving-investment account, so the separate treatment of stock is not required. Therefore, Equation 4-25 provides the investment demand framework in the model.

$$QINV_c = qinvbar_c * IADJ_t \tag{4-25}$$

Where:

$qinvbar$ = Base-year fixed investment

$IADJ_t$ = Adjustment factor

4.8.5 Government Revenue

Government revenue is the sum of income received by the government through various sources. The domain of government revenue equation constitutes as direct taxes on households, import tariff on the commodities that enter in the country, and the foreign aid or any other transfers to the government. Equation 4-26 is the government revenue equation that sums up all these transactions into the modelling framework.

$$\begin{aligned} YG_t \quad & \sum_{f} YH_{ht} * ty_h + EXR * tr_{GOV\ ROW} + \sum_{c \in CM} (tq_c * PQ_c * QD_c) + (PM_c * \\ & + \sum_{c \in CM} tm_c * EXR * pwm_c * QM_c + \sum_{c \in CE} te_c . EXR . pwe_c * QE_c \end{aligned} \tag{4-26}$$

There are several other entries that can be included in the government revenue equation e.g. value added tax, activity tax etc.; however, we included only those entries that are part of our SAM. The remaining factors like value-added tax are not included because in Pakistan value-added tax is not implemented yet.

4.8.6 Government Expenditure

The sum of total government spending on consumption and transfer constitutes the government expenditure bill as shown in the Equation 4-27. However, in the case of climate change the damages incurred due to climate change is also regarded as expenditure, therefore, gross damages are also part of the equation of government expenditures.

$$EG_t = \sum_c PQ_c . QG_c + \sum_h tr_{h\,GOV} . \overline{CPI} + GD_t \qquad 4\text{-}27$$

Where:

EG_t = Government spending

CPI = Consumer price index (Numeraire)

4.8.7 Real Gross Domestic Product (GDP)

Real GDP equation comes last in institutional module equations. In the calculation of real GDP, climate change is taken into account because climate change implicitly reduces real GDP. Equation 4-28 provides the framework for the calculation of real GDP by incorporating climate damages.

$$RGDP_t = \sum_c \left(\sum_h QH_{ch} + QG_c + QINV_{ct} \right) + \sum_c QE_{ct} - \sum_c QM_{ct} - ND_t \qquad 4\text{-}28$$

Where:

ND_t = Net damages due to climate change

4.9 Climate Change Module

For quantifying the costs and benefits of environmental policy CGE models are considered the best available tool. The aim of the CGE model is to simulate how economic activity affects the environment and vice versa. The climate change module is an additional element in a classical CGE model; its equations are derived from the standard DICE model (Nordhaus, 2008). These equations can be divided into three broad segments namely: objective function equations, economic activity equations, and geophysical equations. The first segment of the equation represents the standard modern theories of optimal economic growth, in which baseline attempts to project growth level of economic and environmental variables without any climate change policies. Therefore, in technical terms income and prices are considered consistent with the competitive market equilibrium and known as "Negishi prices and incomes". In the next section, a set of equations determine the evolution of output over time. In our model, we presented production with a slight modification in the standard neoclassical production function.

In addition, it is assumed that production function exhibits constant returns to scale in the factor of production i.e. capital and labour. Likewise, we incorporated climate damages and Hicks-neutral technical change in the production function. In the final section economic activities are linked to geophysical parameters. The building of such linkage is quite challenging because geophysical parameters have inherently complex dynamics and demand parsimonious specification of the theoretical model with empirical and computational compliance.

4.9.1 Radiative Forcing

The earth's surface becomes warm due to the accumulation of GHGs that exert radiative forcing. Equation 4-29 represents the relationship between GHGs accumulation and radiative forcing. The radiative forcing equation calculates the impact of GHGs accumulation on the radiation balance of the globe. The DICE model equation with slight adjustments is given below.

$$F_T = \eta \left\{ \frac{\log M_{AT}(T) + 0.000001/596.4}{\log(2)} \right\} + F_{EX}(T) \qquad \text{4-29}$$

Where:

F_T = Radiative forcing

η = Temperature forcing parameter

$M_{AT}(T)$ = Atmospheric mass of carbon reservoir

$F_{EX}(T)$ = Exogenous radiative forces

4.9.2 Damage Function

The impacts of warming usually enter a CGE model as monetary damages. Aggregate monetary damage is a model as a function of a climate variable. It is assumed that damages are proportional to the output and likewise polynomial functions of mean temperature change. Equation 4-30 estimate potential costs of catastrophic damages. It is clear that this equation is extremely conjectural, given the thin base of empirical studies on which it rests. In the case of Pakistan, damage equation from DICE model is downscaled and represented as a function of real Gross domestic product (RGDP).

$$\Omega_T = RGDP(T) * \left(\varphi_1 * T_{AT} + \varphi_2 T_{AT}^{\varphi_3}\right) \qquad \text{4-30}$$

Where:

Ω_T = Climate damages

φ_1 = Damage intercept

φ_2 = Damage coefficient

φ_3 = Damage exponent

T_{AT} = Global mean surface Temperature

4.9.3 Atmospheric Carbon Concentration

Carbon concentration is the main source that influences temperature and climate change. The basic DICE-1999 model carbon cycle is based upon a three-reservoir i.e. the atmosphere, upper oceans, and deep oceans. It is assumed that each reservoir is well mixed with each other in the short run, however, mixing between the upper reservoirs and the deep oceans is slow. Equation 4-31 and 4-32 represents the equations of the carbon cycle. Both of the equations simplify what are inherently complex dynamics. However, they have some limitations to represent the complex interactions of ocean chemistry and carbon absorption.

$$\mathrm{MAT}_{(T+1)} = MAT_T * b_{11} + MU_T * b_{21} + E_T \qquad 4\text{-}31$$

Where:

$\mathrm{MAT}_{(T\cdot}$ = Atmospheric concentration of Carbon

b_{11} = Carbon cycle transition matrix

b_{21} = Carbon cycle transition matrix

E_T = CO_2-equivalent emissions GtC

Subsequently, average carbon concentrations between two different time horizons are calculated. Equation 4-32 provides the average concentration of carbon dioxide given the two different time scale of atmospheric carbon concentration.

$$\mathrm{MATAV}_{(T)} = (MAT_T + MAT_{T+1})/2 \qquad 4\text{-}32$$

Where:

$\mathrm{MAT}_{(T+1)}$ = Carbon concentration in atmosphere GtC

From the above equation, it is clear that when carbon dioxide emissions increase by a certain amount it creates an exogenous shock, which leads to an increase in the global mean temperature compared to its initial level. Usually, a carbon dioxide doubling compared to pre-industrial time leads to a temperature increase by 2.5 to 3°C above present temperature level[19] (Pearce et al., 1996).

4.9.4 Atmospheric Temperature

Atmospheric temperature equation is used to measure the relationship between the accumulation of GHGs and climate change (Nordhaus, 2008). Therefore, the basic DICE model adopts a small structural model to capture the basic relationship between GHG concentrations, and the dynamics of climate change. The increase emission of GHGs warms earth's surface by increasing radiative forcing as shown in the Equation 4-29. Radiative forcing warms atmospheric layers and causes a lag effect in the system due to diffusive inertia between different layers. Although, radiative forcing and emission tends to overestimate historical temperature changes, but it ties up with IPCC projections. The Equation 4-33 and 4-34 represents surface and initial temperature.

$$\mathrm{TATM}_{(T+1)} = \mathrm{TATM}_{(t)} + C_1 * \left(F_{t+1} - LAM * TATM_t - C_3(TATM_t - Tocean_t)\right) \qquad 4\text{-}33$$

Where:

LAM = Carbon concentration in atmosphere GtC

C_1 = Climate-equation coefficient for upper level

C_3 = Transfer coefficient upper to lower stratum

Likewise, Equation 4-34 provides an initial condition for atmospheric temperature.

$$\mathrm{TATM}_{(T)} = \mathrm{TAT\ M}_{(0)} \qquad 4\text{-}34$$

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[19] The recent COP21 declaration call for temperature cap at 1.5ºC.

4.9.5 Adaptation Cost

Adaptation cost is the first part of the third section in the climate module equations. Equation 4-35 gives the framework of calculating adaptation cost, which is multiple of real GDP.

$$\mathrm{ADPC}_{(T)} = RGDP_T * \mathcal{E}_1 AL_T^{\mathcal{E}_2} \qquad \text{4-35}$$

Where:

AL = Adaptation level

$\mathcal{E}_1 \& \mathcal{E}_2$ = Fraction of output per adaptation level

4.9.6 Residual and Net Damage

Residual damage is the first step in the calculation of net damage. Firstly, gross damages are multiplied with adaptation level. Subsequently, residual damages are added with the adaptation cost to obtain net damages. The Equations of residual and net damages (4-36, 4-37) are as follows:

$$RD_{(T)} = GD_T * (1 - AL_T) \qquad \text{4-36}$$

Where:

$RD_{(T)}$ = Residual damages

GD_T = Gross damages

Adaptation is usually included implicitly in the aggregate monetary damage function (Tol & Fankhauser, 1998). Net damages are the summation of adaptation costs and residual damage.[20]

$$ND_{(T)} = RD_T + ADPC_T \qquad 4\text{-}37$$

4.9.7 Consumption Equation

In the basic DICE model consumption is considered as “generalized consumption” that includes marketed and non-marketed goods and services. In the basic consumption equation, investment is subtracted from the output, however, we substituted investment with adaptation cost and net damages that limit consumption of output. Since damages are linearly linked with GDP, this linear relationship can be influenced by further factor shifting a number of damages up or down. In most of the cases, damages are fed back by simply subtracting monetized market damage from the total output (Tol & Fankhauser, 1998). In this case Equation 4-38 shows the calibration of consumption.

$$CC_{(T)} = RGDP_T - ADPC_T - ND_T \qquad 4\text{-}38$$

Where:

$CC_{(T)}$ = Net consumption

ND_T = Net damage

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[20] As adaptation cost is zero that equate net damages with residual damages.

4.10 System Constraint Module

The final set of the equations in the model constitute “equilibrium conditions” or “system constraints”. In the decision-making process equilibrium must be satisfied without any exogenous interference. A competitive model equilibrium is defined as a set of prices at which excess demand/supply is zero. Therefore, in a market economy, the price is the equilibrating variables that vary to achieve market clearing. The equilibrium and corresponding equation of all the relevant systems are presented in the following section.

4.10.1 Factor Markets Equilibrium

Equation 4-39 shows the equilibrium between the total quantities of factor demanded and supplied. The supply of the factor of production is fixed in the basic model version, while demand is flexible. As mentioned above, the wage is the equilibrating variable that assures market equilibrium. Any increase in the factor wage raises the wage paid by each activity, while it is inversely related to the factor quantity demand. The factor market equilibrium equation is given below, the right-hand side of the equation shows fixed supply of labour, as per our assumption that factor of production cannot increase in the short run.

$$\sum_{a \epsilon A} QF_{fa} = \overline{QFS_f} \qquad \text{4-39}$$

Where:

QFS_f = Quantity supplied of factor (Exogenous and fixed)

All factors are considered mobile between the demanding activities. However, for unemployment specification the supply side of Equation 4-39 is made flexible at a given wage of the factor.

4.10.2 Composite Commodity Markets Equilibrium

Equation 4-40 gives the demand and supply equilibrium of composite commodity. The demand side includes intermediate demand, household demand, investment demand, and government consumption demand. The composite commodity supply is compiled from marketed output and imports.

$$QQ_c = \sum_{a \in A} QINT_{ca} + \sum_{h \in H} QH_{ch} + qg_c + QINV_c \qquad \text{4-40}$$

Among all the endogenous terms, qg and QINV are fixed in the basic model version where changes in stock are aggregated with fixed investment. In the composite commodity markets, the market-clearing variables for the import side are quantities of import supply, and two interrelated domestic prices (demand and supply price of the commodity produced and sold domestically).

4.10.3 Current-Account Balance

The current account balance represents country earning and spending balance. Exchange rate acts as an equilibrating variable in the current account balance while foreign saving remains fixed.

$$\sum_{c \in CE} pwe_c . QE_c + \sum_{i} tr_{i\,ROW} + \overline{FSAV} \qquad \text{4-41}$$
$$= \sum_{c \in CE} pwm_c . QM_C + irepat + yfrepat_{CAP} + yfrepat_{LAB}$$

Equation 4-41 illustrates fixed trade deficit, however in cases of flexible trade deficit, the exchange rate may be fixed and foreign savings will be variable.

4.10.4 Savings–Investment Balance

The fourth and final equilibrium constraint is a saving-investment balance. Equation 4-42 states the equality of total saving and investment. The sum of savings from domestic government & non-government institutions, and the rest of the world constitute total saving; however, foreign saving needs to be converted into domestic currency. Additionally, total investment is the sum of gross fixed capital formation and changes in stock.

$$\sum_{h} MPS_h * (1 - ty_h) * YH_{ht} + (YG_t - EG_t) + (EXR * \overline{FSAV}) \qquad 4\text{-}42$$

$$= ygi + (EXR_t * irepat) + \sum_{c \in C} PQ_c * QINV_c + WALRAS_t$$

In the basic modelling framework changes in marginal propensity to save act as a market clearing variable, while keeping other variables fixed. Given these conditions, a balancing role is provided by the saving side of the equation. To make the model square we added WALRAS as an additional dummy variable, with a zero solution value. After this adjustment, the model satisfies Walras law. Finally, we added objective function equation that equals to one.

$$OBJ = 1 \qquad 4\text{-}43$$

4.11 Pros and Cons of the Basic CGE Model

Computable general equilibrium modelling has certain advantages over counterpart quantitative methods. These models have the potential to capture a much wider set of economic assessments. One of the major advantages of CGE models required detailed data for an economy for only one year while econometric models need time series data sets. This enhanced their scope and range of utilization. This makes CGE models more effective in developing countries, where economic system are susceptible to drastic changes (Hosoe et al., 2010).

Moreover, price changes in CGE models cause simultaneous reactions in other markets like all general equilibrium models. For the sake of the micro foundation,[21] and the inclusion of economic feedback processes make CGE models useful for long-term perspective analysis (Walz & Schleich, 2009). Additionally, these models can incorporate dozens of industries simultaneously, while in the case of other modelling techniques it demands a huge data set. Last but not the least is the transparency and numerical solvability of CGE modelling that bridges the gap between, planner, theories, and policy makers while handling complex multi-sector and regional issues. Moreover, these models are theoretically consistent and necessitate an abstraction from the real working of an economy.

In contrast, CGE models have some shortcomings also. First is its estimation process or calibration is highly sensitive. It can give spurious results in the case of an economy with significant fluctuations. Secondly, estimating CGE model parameters is like taking a still snapshot from a dynamic reality. It can be theoretically inconsistent when a dynamic component of an economy such as saving and investment are also incorporated. The third disadvantage of CGE model is the rare incorporation of financial/monetary aspects. Moreover, CGE models focus on the real side of the economy hence they deal in relative prices instead of absolute prices (Hosoe et al., 2010).

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[21] The micro foundation consists of three conditions, namely market clearance, zero profit of firms and income balance of the households.

4.12 Applications of GE Models

In this section, we presented a brief list of research areas where CGE modelling is applicable. This shows the importance and wide range of CGE model applications. Applied general equilibrium or CGE models are applicable to analyze general macroeconomics issues like public expenditure cuts, tax and trade reforms impacts on income distribution.

- To analyze fiscal policy issues like value added taxes reforms.
- In the field of international trade policy issues like WTO negotiations, import barriers etc.
- To analyze pros and cons of regional and transport policy.
- Environmental policy issues like eco-taxes introduction, implementation of CO_2 emissions taxes etc.
- In the analysis of industrial and labour policies, deregulations of power tariff, the influx of foreign workforce inflows.

4.13 Social Accounting Matrix (SAM)

This section describes the construction of the Social Accounting Matrix (SAM) 2012 for Pakistan’s economy. This SAM will be used as the underlying data for the CGE model, described in the previous section. Thus, it reflects sectors and institutions that are used in the CGE model. Since SAM is an extension of Input-Output (IO) table, therefore, we start by introducing IO tables. Succeeding that consolidated SAM is given to illustrate its main components along with a description of the dataset used. SAM is the starting point of any CGE model as it offers a structural and empirical framework of the model. Provided that, it is assembled before constructing a CGE model in order to determine potential scope of study and data availability. However, it is often revised according to the different questions, arises during model construction. In any economy at equilibrium SAM highlights basic accounting identities and ensures that entire economy expenditure equals to income; furthermore, no actor can spend more than its corresponding earning. Likewise, in an economy-wide model SAM defines all of the accounts that specify the circular flow of income, on which core equations of CGE model are determined.

4.14 Overview of the Input-Output (IO) Tables

For a particular country or region, IO are used to organize data which present a static image of the economy. However, it does not serve the purpose of a model to analyze the working mechanism of an economy. In contrast, it contains benchmark information for the formation of a credible model. In any economic system, IO holds the information of market resource allocation on which a variety of general equilibrium models can be created. As a matter of fact, modern computerized economic techniques improve the original input-output analysis as developed by Leontief (1936). In any particular economy, IO are made to describe the flow of goods in the economy among various sectors. In a given period of time, they represent the value of economic transactions, which is further broken down to intermediate and final use.

Furthermore, IO provides detailed cost structure of production activities. (Konovalchuk, 2006). A standard general structure of the IO is shown in Table 4-1. This general structure mostly opts in the construction of any IO e (Eurostat, 1986). The standard IO can be segregated into 10 different quadrants, each of them processes a distinguished type of properties. Generally, rows of the IO shows the output of a particular sector which is being consumed as intermediate input by other sectors as input, while columns represent the inputs of a sector that are obtained from other sectors. If the IO is balanced the row sum will be equal to column sum.

In the case of Pakistan IO quadrant “A” is composed of 82 sectors, among these 82 sectors 15 sectors constitute Agricultural, 3 sectors belong to mining, 38 sectors belong to Manufacturing while the remaining 24 constitute Service sector. Similarly, “B” shows products from the industries to the end-use consumers and this is called "final demand" or "gross product consumed." The displayed column depicts the total spending by households, governments, changes in industrial stocks, and investment, as well as net exports on consumption of final goods and services. Correspondingly, quadrant “C” gives the total domestic production information which is the sum of production sector and final demand. The information regarding the imports of goods and services is given by the D, E, and F quadrant. The payments to factors of production and taxes are presented in “G” and next to it is quadrant “H” which usually remains empty.

The row summation of both G and H gives the quadrant “I”, which represents the value-added information. Specifically, it captures the payment flows from each industry to their own primary factors like salary and wages for labour; indirect business taxes; dividends, interest, and rents; capital consumption allowances (depreciation); other property-type income (like profits); and purchases from foreign suppliers (imports). Finally, the “J” gives the information of inputs, moreover, if the IO is balanced then the columns of quadrant J and the rows of quadrant C should be same i.e. total input equals to output for the production sector (Rutherford & Paltsev, 1999). In terms of Table 4-1 the information relating to ‘H’ matrix is available in SAM, which facilitates the further explanation of the inter-linkages between all the accounts (Pyatt, 1988).

Table 4-1 General Input Output Table Structure

		Intermediate Consumption					Final Consumption				Output
		Production Sectors					Private consumption	Government consumption	Investment	Exports	
		1	2	i	:	N					
Domestic Production	1	A					B				C
	2										
	i										
	:										
	n										
Imports	1	D					E				F
	2										
	i										
	:										
	n										
Value Added		G					H				I
Labour											
Capital											
Indirect tax											
Input		J									

4.14.1 Advantages of IO

There are abundant features of the IO that clearly distinguish it from other counterparts. These features have lasting value to its direct descendants and to other models. The simplicity and transparency of this table are its strengths rather than weaknesses. A few vital advantages of these IO are explained below:

1. IO are firmly grounded on the technological relations of production.
2. They are based on measurable quantities that are empirically viable and verifiable.
3. The unique sectoral scheme with a matrix representation of an IO facilitates data collection and organization.

4. IO facilitate the ability to analyze the potential impacts of private-sector decisions and public-sector policies by applying Leontief multipliers (Richardson, 1985)
5. IO are at the core of the universal System of National Accounts, by providing a full accounting for all inputs into production.
6. IO also made possible the extensive work in the environmental analysis using other models, most notably with (Hudson & Jorgenson, 1974), precursor to CGE analysis.
7. IO has been a mainstay of regional science since the mid-1950s and over the past two decades become increasingly popular among agricultural economists.

4.15 Social Accounting Matrix (SAM)

The social accounting matrix (SAM) is a new tool for economic analysis as compared to its old counterpart IO that ensures aforementioned conditions of the desired data set. The inception of the modern use of SAM as conceptual framework begins in 1970’s; however, later on, they are widely used to address many developmental issues like income distribution, structural adjustments, and poverty. The mode of data organization in SAM is most suitable to keep track of the circular flow of income and expenditure in an economy (Richardson, 1985).

SAM represents data in matrix form, which shows the micro and macro transactions record of a socio-economic system. In particular, it captures the transfers and transactions among all agents in the economic system. It simplifies the national accounts for a specific country, though it can be extensive and can incorporate multi-national accounting flows. It can be constructed for whole regions and even in a global context. It recognizes all monetary flows from sources to recipients, within a disaggregated national account. As a matter of fact, SAM is a comprehensive economy-wide set of accounts, which is internally consistent and quantify economic transactions within an economy by a single-entry accounting system (Pyatt & Round, 1985). Each account in SAM ensures total revenue equated with total expenditure i.e. row total equals to column total, which fulfills the underlying principle of double entry account keeping (Lofgren et al., 2002).

The data sources used to build SAM are IO of the economy, national accounts, fiscal accounts, the balance of payment information and household surveys.[22] SAM can serve as a unique economic database for structural analysis provided its distinctive capabilities of capturing inter-industry linkages and household income and expenditure compositions. On top of that, it is consistent with macroeconomic accounts (Round, 2003). Overall, SAM provides a base of a consistent multi-sectorial economic data for the development of economy-wide models and further policy analysis (Löfgren et al., 2001).

In particular, six different types of accounts are recorded in the SAM matrix, namely activities, commodities, factor or production, institutional agents, capital and rest of the world. Activity and commodity collectively grouped as production account. The structure of a consolidated SAM is given in Table 4-2 that indicates various different accounts.

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[22] Household survey contains detail information on the composition of household income and expenditures.

Table 4-2 Consolidated SAM

i.

4.16 Social Accounting Matrices of Pakistan 2012

In the case of Pakistan, the number of SAM are very few, and mostly based on IO of 1990/91 or even earlier. The lack of SAM numbers is not a serious problem for stable economies; however, for rapidly growing or changing economies such a lag can create significant limitations. Table 4-3 shows previously constructed matrixes for Pakistan. Debowicz et al. (2013) constructed the latest SAM for Pakistan which provides comprehensive details on the economic structure of the country. In this SAM production activities are disaggregated into 51 activities, household into 18 household groups, and factor of productions are disaggregated into 27 groups. This extensive disaggregation allows the tracing of direct and indirect effects of potential scenarios through production and consumption linkages which further facilitate to capture distributional effects.

For the construction of aggregated SAM, the disaggregated IO data is reconciled. The reconciliation is basically made in line with the study objectives. More specifically we built a desegregated SAM which integrates between sectors and captures the financial and capital flows from local and abroad. This structures of the SAM will enable an explicit presentation of the impacts of various shocks on Pakistan economy in general and the agricultural sector in particular. The data source for the construction of SAM are quite diverse in nature and correspond to different periods of time, therefore, they often present inconsistencies.

Table 4-3 Previous SAMs for Pakistan

No.	Name of researchers or organization	Salient Features
1	Pakistan Institute of Development Economics (1985)	• Base year: 1979
2	(GoP, 1993)(FBR)	• Base year: 1984/1985 • Households: 1
3	Siddiqui and Iqbal (1999)	• Base year: 1989/1990 • Sectors (5): agriculture, industry, education, health, other sectors • Factors (2): labour and capital • Agents: households (8), firms, government, rest of the world
4	Dorosh et al. (2004) (DNN)	• Base year: 2001/2002 • Sectors (34): agriculture (12), industry (16), services (6) • Factors: 27 • Agents: households (19), enterprises, rest of the world, government
5	Waheed and Ezaki (2008)	• Base year: 1999/2000 • Sectors (6): agriculture; mining and quarrying; manufacturing; electricity, water, and gas; construction; other sectors • Factors (2): labour and capital • Agents: households (1), firms, government, commercial banks, central bank, rest of the world
6	Debowicz et al. (2013)	• Base year: 1990/91 • Sectors (51) • Factors (27) • Household (18 groups)

Source; Extracted from literature

This inconsistency between IO, national, and other government accounts' data is not desirable for the construction of the SAM. Before going into detail of the aggregation process it is important to highlight the importance of the selected base year i.e. 2012. The main reason for selecting 2012 as the base year to construct SAM is the availability of the latest data. The latest available national household expenditure survey (HIES) was conducted in that year. Furthermore, our study primarily focuses on the agricultural sector, and the latest published agricultural statistics of Pakistan are also available for the year 2012.

4.16.1 Data Dimension

The primary data source for this study is the IO, where national accounts, HIES, and the economic survey are the supporting data sets. All these data sets are formalized in a consistent framework following the standard expenditures and saving patterns. Typically, a highly aggregated SAM is constructed based on IO and other sources. Unfortunately, the most recent available IO is for 1990-91, and the value added estimates by sector are even based on earlier IO.

The original IO consist of 82 production industries/sectors and 8 non-production sectors. Among these 82 sectors, 15 sectors belong to agriculture, 03 sectors of mining, 40 sectors of manufacturing and 24 service sectors. However, to meet the research objectives and for consistency of activities classification as well as to facilitate the interpretation of results, all sectors were regrouped into 17 sectors. This higher level of aggregation is based on our research objectives, which focus on the agricultural sector in particular. Therefore, we aggregated 40 manufacturing and 3 mining sectors into one industrial sector while 24 services sector are aggregated into 1 service sector. All the agricultural sector activities are maintained in the original form as per IO to figure out the effects of external shocks (climate and technical change) on the agricultural sector of the economy.

4.16.2 Construction Proto-SAM

Extension of the IO to a SAM is carried out by making Proto-SAM, which is the first SAM that we built by aggregating the IO according to our objectives. Furthermore, we assume all the exogenous accounts of column coefficient are constant. Thus, in formulating 2012 SAM it was necessary to construct a consistent set of accounts for production and value added by sector based on the1990/91 IO.

This entire process of constructing SAM can be done in two steps: first, we constructed a "Proto-SAM" by aggregating the sector from IO 1991 and other sources.[23] The transaction flows and transfers between all economic agents, financial flows, and institution in the system taken place in the given year (2012) will be captured by Proto-SAM. Precisely, Proto-SAM classifies economic relations through four basic accounts (i) activity and commodity. (ii) two factors of production such as labour and capital, (iii) current account transactions between households, government, and the rest of the world, and (iv) one consolidated capital account to capture the flow of savings and investment by institutions and sectors respectively.

In the second step, we updated and balanced the SAM by applying a series of adjustments. We constructed the aggregated SAM to consist of 17 sectors, in which 15 agricultural sectors and the remaining two are the aggregated sector from mining, manufacturing, and services. Table 4-4 presents the balanced and updated SAM for Pakistan.

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[23] 1990-91 Input-Output Table (97 sectors), 2011-12 National Accounts, 2011-12 Pakistan Integrated Household Survey, 2012 Pakistan Rural Household Survey, 2011-12 Pakistan Economic Survey (sector/commodity data on production, prices, trade).

Table 4-4 Balanced SAM 2012

This SAM is highly based on Pakistan national account statistics of 2012 published by the department of statistics Pakistan. The process of balancing and updating SAM is presented in the following section.

4.17 Balancing of Proto SAM

Once we construct a highly aggregated SAM, the next step is it’s balancing i.e. equating the total value of columns by rows respectively. As stated earlier, a SAM is built by the combination of distinguished economic ideas i.e. input-output framework and national accounting framework, therefore, it presents inconsistencies. The input-output framework shows how the output of one industry is actually an input to other industry. Likewise, it represents the purchase of one industry intermediate input as the sale of another industry output.

In the national accounting framework, SAM represents a square matrix where the inflows (receipts) and outlays (expenditures) for each account are shown as a corresponding row and column of the matrix. Basically, it is an accounting framework, where total receipts (rows) and expenditures (columns) for each account must be balanced to ensure the principles of double-entry book-keeping. The transactions between accounts are presented by the cells and each cell shows a payment from a column account to a row account.

To obtain a macro balance, each of these accounts must be balanced i.e. total columns side equal to the total rows side or the outlay should equal to receipt. In order to make SAM as a proper data set for a standard CGE model, some modification needs to be done. This modification will reconcile the SAM with the CGE framework. This reconciliation is crucial prior to setting the stage for the core model. In the construction of a balanced SAM for Pakistan, we come across the classic problem of estimation. Since the available input-output table is for the year of 1990-91, while based on national accounts dataset we have new information on rows and column sums of SAM. Therefore, the problem of updating the IO matrix will be a key concern due to lack of information regarding input-output flows.

The RAS method (named after the economist Richard Stone[24] (1919–1991)) of balancing and updating the SAM is the most widely known and commonly used automatic procedure. The RAS method is basically an iterative process; here columns and rows are successively forced to add up with margin totals, then simultaneously it equates the balancing value of rows and columns to zero (0). According to Bacharach (1970) `RAS' method works in a unique set of positive multipliers (normalized) which satisfies the bi-proportionality condition. However, RAS method of balancing becomes inefficient when an information gap exists. For example, if information on the row and column sum are available, identification of the coefficient become difficult. Additionally, updating in this framework becomes a special case provided that SAM needs to be balanced with new row and column totals (Löfgren et al., 2001).

To handle such ill-conditioned problems of RAS method Golan et al. (1996) suggest a variety of estimation techniques using maximum entropy econometrics. The cross-entropy (CE) method of balancing is based on information theory of Shannon (1949) which is applied by Theil (1967) in economics. CE method of balancing SAM is considered superior if the analysis is concerned with column coefficient, else both the methods are equally efficient. However, RAS method performs slightly better if the focus is on the flows in the SAM. Similarly, the CE approach works efficiently when minimum

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[24] One of the co-authored for the 1968 SNA together with Abraham Aidenof.

information is available. The CE approach has an added advantage of minor manual adjustment which makes it user-friendly (Löfgren et al., 2001).

Since we are focusing on updating the internal coefficients of SAM and balancing it simultaneously, with little available information, the RAS method is therefore not suitable in this regard. As a result we adopted CE method of balancing. As mention above, initially we construct a Proto-SAM using different data sources, which are inconsistent and make SAM account imbalance. In the initial stage, large imbalances are found across all the sector. Therefore, following the procedures adopted by Debowicz et al. (2013) we performed a series of adjustments. The internal coefficients[25] for agriculture, labour, capital, and trade were estimated, the coefficients for taxes were obtained by residuals which reduced the imbalance to less than 35 per cent.

Furthermore, we balance this Proto-SAM by applying a CE method which minimizes the CE distance between the imbalance and balanced Proto-SAM. In this case, each cell in the Proto SAM specified to have an error support set, whose weights are estimated to minimize the CE distance between balanced and imbalanced SAM (Golan et al., 1994). The process is congruent as described by Löfgren et al. (2001) with some key differences i.e. previously, negative cells and accounts with zero sum in the SAM demand special treatment. Here we apply a modified approach developed by McDonald et al. (2007) that includes only probability weights for selected error support set, and negative entries and zero sum accounts need no special treatments.

The highly aggregated SAM for Pakistan economy is built following the above mentioned procedure. We have gone through a series of steps from making Proto-SAM

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[25] For the detail estimation procedure refer to (Dorosh et al., 2003).

until there was a final balanced and updated SAM. The final aggregated and balanced SAM for Pakistan is given in Table 4-4.

4.18 SAM Market Closure

The balanced and updated SAM must satisfy three conditions of market closure. The conditions are further explained below:

4.18.1 Market Clearing Condition

In the SAM we come across two different markets, one is commodity market and other is factor market. In the standard balanced SAM both the market's demand and supply must be in equilibrium. In the case of the commodity market, the quantity of each commodity Q_i produced by i producers will be equal with the commodity demanded by j producers in γ_i industries. The industrial demand of producers absorbs commodities to fulfill the final demand F_j by utilizing it as an intermediate input Z_{ij} in their production process. Similarly, the equilibrium in factor market implies that all industries in the economy must be fully employed with the factor endowments available in the market. In other words, the quantity of primary factors supplied by economic agents X_i should fulfill the demand of all representative producers.

4.18.2 Normal Profit Condition

The second condition of market closure is the assurance of normal profit. The normal profit condition assumes that all industries will receive zero profit. Whereas, the value of output Q_i produced must equal the value of primary factors X_i plus intermediate inputs Z_{ij}. Conversely, we can say that total revenue must be equal to total cost. Granted that profit is a monetary term, therefore, the total revenue will be obtained by multiplying output price P with output quantity Q_i. Similarly, the total cost is calculated by the multiplying price of intermediate input P^i with the quantity of intermediate input and adding it to the cost (W_f) of value added.[26] Mathematically it can be demonstrated as shown in equation 4-44.

$$\sum P_i Q_i = \sum_{i=1,j=1}^{n} P^i Z_{ij} + \sum_{J=1}^{n} W_f . X_i \qquad 4\text{-}44$$

4.18.3 Factor Market Balance

According to factor market balance condition, the value of product payment V_j (total value added) must be equal to the factor income m received by the factor endowment agents. Furthermore, it should be equal to total final demand F_j and factor expenditure on goods and services. Ultimately, this condition ensures that the sum of the elements of V_j is income which in turn equal to the elements of final demand F as shown in Equation 4-45.

$$m = \sum_{j=1}^{n} V_j = \sum_{J=1}^{n} F_i \qquad 4\text{-}45$$

All the above mentioned balancing relations basically ensure the circular flow of the economic system. Since SAM is a generalization of IO that extends information beyond the structure of production to distribution of income. It provides information on the distribution of value added generated by production activities, patterns of saving investment and consumption, and household institutional accounts. In other words, SAM integrates different data sources like national accounts, IO, HIES and other relevant data

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[26] In this case the average cost of value added is assumed.

sets to show income of household and distribution of operating surplus between different institutions. Thus, it forms a consistent framework for the expenditure and saving patterns. In essence, the information of SAM regarding the linkage between factors and household income is a unique and important feature of SAM.

4.19 Calibrating the CGE Model

In the applied general equilibrium models calibration of the model is done in order to reproduce base year data as a model solution. However, for the key model parameters, the process of calibration must be augmented from literature (if there is a lack of data). In practice, key model parameters are considered synonymous with elasticities due to extensive application of CES/CET function in applied models. Calibration technique will estimate the related coefficient parameters from benchmark data in order to standardize that parameter that is used in the calibration technique. Demand and cost functions are used in order to describe behavior patterns of producers and consumers. These functions are derived from Cobb-Douglas, stone-Geary and CES (single stage or nested) production function. In some of the cases most complex variants like Leontief function also can be considered; however, they demand more execution time for equilibrium calculation.

In this case, standard SAM procedures need additional parameter values to carry out the estimation and simulation using CGE modeling. Once the operators are identified and their optimization behavior is identified by algebraic equations, the parameters in the equations should be evaluated. Data on exogenous and endogenous variables at a given time is used for this purpose. For the development of CGE model two types of parameter estimate have been used first is econometric approach introduced by Berndt and Christensen (1973) to generate base year equilibrium observation, and the second calibration approach led by (Jorgenson & Wilcoxen, 1991).

Calibration procedure uses equilibrium condition of the model and benchmark equilibrium data set to solve for parameter estimates. The method relies on the assumption that the economy is in equilibrium. As mentioned before benchmark data set represents equilibrium of the economy, therefore, the model is actually solved from equilibrium data for its parameter values. Shoven (1992) compiled SAM systematically that represents the benchmark data set. Equilibrium exists because the SAM is square and row column sum of a given account are equal (Pyatt, 1988).

When the parameters are estimated correctly, the result using the initial data become close to the base year equilibrium data. In case the results are not identical, it is necessary to modify the model until it can replicate the base-year observation. Nevertheless, the calibration approach has been criticized for the following reasons: (i) the parameter estimated are deterministic in nature, and therefore, there is little to support the realism of the coefficients; (ii) the estimation of the parameter is a function of the benchmark year selected. In case there is any error in parameter estimations the result using the initial data will not match with the base year equilibrium data, therefore, it is necessary to modify the model until it can replicate base year observation.

Despite these negativities of the calibration approach it remains the first choice for many researchers due to various reasons (Sánchez & Vos, 2007). First, in the case of scarce data availability (especially in developing countries), the simultaneous stochastic estimation of all these parameters would be unrealistic. Therefore, calibration is needed to avoid severe restrictions (Gunning and Keyzer, 1995; Lau 1984). Secondly, the calibration method is fruitful because the small data set is needed for parameter estimation. Finally, CGE is more applicable to least developed countries (LDCs), therefore, calibration approach is widely used due to the infeasibility of full-fledged econometric estimations.

SAM has been widely used as a data for calibration. So, in the present study, the calibration approach is used to determine the model's parameter. For solving parameters, the model and equation are written in General Algebraic Modelling System (GAMS) language. The GAMS has been developed to solve this type of model, thereby making the process of programming and running CGE models even simpler. GAMS is a software specifically designed to solve linear, nonlinear, and mixed-integer problems and designed to make economy-wide complex mathematical models easier to construct and understand. The main advantage of GAMS is that it allows modelers to use an almost standard notation (Al-Amin et al., 2008).

4.20 Summary

The first part of the chapter sheds light on the general equilibrium theory and conceptual framework of the study. It ties up the relevant theories as discussed in the literature review chapter to formulate a conceptual framework for the study to achieve set objectives. Therefore, this chapter provides the empirical framework to gauge the potential of technical change in redressing climate damages from the agricultural sector. For this purpose, it elabourates upon an Integrated Assessment Model (IAM) approach. The core equations modules of the model are rooted on the Computable General-Equilibrium (CGE) model while, climate module equations are taken from the DICE model, which make it robust and competent.

The second part of the chapter mainly covered the data dimensions of the study. It explains the IO and its advantages for empirical analysis. It further goes on to elabourate on the formulation of SAM, which is a benchmark data set for the analysis. The outdated data set pose challenges for updating and balancing SAM; however, after conducting a series of adjustments and applying a cross entropy method SAM was balanced and updated close to the economy. This chapter ended with expounding SAM market closure conditions. In addition, the process of CGE model calibration is explained briefly.

CHAPTER 5: IMPACTS OF CLIMATE CHANGE ON AGRICULTURAL PRODUCTION

5.1 Introduction

This chapter explains the impact of climate change on agricultural production in Pakistan. It explains the monetary damages of climate change on all the downstream agricultural sectors. It begins with expounding the policy scenarios that are taken into account for the analysis and extends the simulation. Proceeding further, it explains the Climate Impact (CI) scenario results that highlight the economic damages on the overall economy, agriculture, and agricultural sub-sectors. The final section of this chapter brings into discussion the results of the CI scenario, by comparing climate damages to Pakistan with regional and global averages.

5.2 Policy Scenarios

The focus of this study is only Pakistan; however, some analogies can be formulated for other countries. The choices of simulation for this study are driven by the real and practical issues in Pakistan agriculture. The study opted for CGE framework for the analysis. Under this framework several types of Integrated Assessment Models (IAMs) can be found. However, the well-recognized model in this realm of research is the DICE model, introduced by Nordhaus (1993). Moreover, it has some extended versions which consider adaptation as a decision variable (De Bruin, K. C. et al., 2009).

To conduct simulations analysis for Pakistan different assumption are made. One of them is that the economy adjusts to any external shock, considering the selection of which variables are exogenously fixed or shocked and, which may endogenously adjust. From a macroeconomic point of view, primary factor markets are among the most important markets. As a result of implementing neutral technical change actions, commodity and price markets may adjust quickly; however, primary factor market adjusts according to time considerations. Therefore, to address the issues regarding lack of clear knowledge about the reactions of these factors of production, three main scenarios are considered in this study as listed below:

a) Baseline Scenario (BL).
b) Climate Impact Scenario (CI).
c) Technical Change Action Scenario (TC)

5.2.1 Baseline Scenario (BL)

In the baseline or business as usual scenario, it was assumed that climate change doesn't have any negative effects on the economic performance of the country. Furthermore, it is considered that economy continues to grow with the existing trend.

5.2.2 Climate Impact Scenario (CI)

In CI scenario, the worst possible effects as a result of climate change are projected. Additionally, it is assumed that neither stakeholder comes up with any response to climate condition via any curative policy. Hence, this scenario projects the output of the country under the adverse effects of climate change.

5.2.3 Technical Change Action Scenario (TC)

The third scenario of simulation represents the response action to climate change. In this scenario, an optimum technical change (Hicks’s Neutral) opts as a mitigation action with its associated costs. Thus, this case highlights the economic impacts of technical change. Also, the comparative analysis of CI and TC fulfills our objective to measure the effectiveness of the technical change in terms of its economic impacts.

5.3 Simulations Description

Within each scenario, a different simulation is performed. The first simulation begins under the CI scenario. The impacts of climate change resulting from carbon emissions and temperature change have been illustrated. The rationale of this simulation is to highlight the monetary damages caused by climate change in general and particularly in agriculture.

Since, in the case of Pakistan, the appropriate rate of neutral technical change that can redress climate damages is not determined. Therefore, this study proposed Hicks's neutral technical change as a measure for reducing climate damages in Pakistan. The second simulation imposes neutral technical change rate, while designing a compensation plan. The motivation for this simulation is to understand how macroeconomic impacts of technical change would change monetary damages of climate change. The third simulation is complemented by climate damages removal. In this simulation, it is assumed that in line with economic conditions the economy works under business as usual conditions.

Finally, the purpose of all the simulations is to ascertain, when a higher level of curing climate damages is targeted, how the effects of technical change be imposed. To do this, in addition to the base simulation, two different simulations analyzed the ramification of climate change and results are then compared.

As a final point, this study estimates the impact of climate change over the period of twenty-five years, which is divided into six-time segments, and each segment is independent of one another. Furthermore, social accounting matrix (SAM) was constructed for the year 2012 hence, it is considered a base year for all the simulations.

Likewise, all the simulations start from this benchmark year and end in 2037. Table 5-1 shows time segments starting from 2012 and ends in 2037.

Table 5-1 Time Segments

S.No.	Time Segments	Years
1	Segment 1	2012-2017
2	Segment 2	2018-2022
3	Segment 3	2023-2027
4	Segment 4	2028-2032
5	Segment 5	2033-2037

5.4 Climate Change and Agricultural Production

To quantify the effects of climate change on the economy of Pakistan in general and in the agricultural sector in particular, the climate parameter of the DICE (Nordhaus, 2008) model was used. Since this study is focusing on a single country, therefore, DICE model parameters have been modified to find the country-specific possible outcomes with regional scope, by adopting the downscaling option. Furthermore, genotype coefficients of the model are downscaled with a focus on the potentially vulnerable impacts under various climatic parameters, such as carbon cycle, carbon emission, carbon concentration, temperature and climatic damage.

Moreover, the downscaled model considers the economic data of Pakistan, and the exogenous data from the DICE model (downscaled for Pakistan), to quantify the impact of climate change on agricultural sector production of Pakistan. In our model, the values of the elasticity for each sector was exogenously taken from International Food

Policy Research Institute (IFPRI) database[27], following Karp and Zhang (2006) who take these values from the Global Trade Analysis Project (GTAP) database. For the consistent growth rate, we took the average of 10 years real GDP growth rate data from World Bank Indicators (WDI) estimates for Pakistan.

By default economic activities cause carbon emissions[28], therefore, carbon emissions have been linked linearly with the economic output. Accordingly, the emissions level for a country will change with continuing economic activities. Thus in our model, net emission value depends on the output or the total production value of a country. Additionally, damage of climate change not only depends on a country's own emissions, rather it depends on cumulative global emissions (Metz et al., 2007) . However, for simplification, we assume zero spillover effect or no externalities. In other words, we assume that the climate damages of Pakistan will only depend on its own emissions. Therefore, considering temperature change as an exogenous shock, we simulated the effects of climate change over the period of 25 years, based on SAM[29] 2012 of Pakistan economy. The assumption of zero spillover effects based on small country assumption, further relaxing this will mislead the results due to the high emission rate of China and India as described in IPCC 2011 report (IPCC, 2011).

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[27] Please see Appendix D for elasticity values.

[28] Carbon emission is used as a proxy for Greenhouse (GH) Gas Emission.

[29] This data base provides a consistent representation of the Pakistan economy.

To begin with, necessary conditions for climate change have been verified i.e. climate parameters are changing or not? In doing so, temperature and emissions trend and magnitude have been identified; as the change in the global mean temperature is allegedly associated with atmospheric GHG concentrations (Allen et al., 2009). Furthermore, the concentration of GHG's are uncertain in the atmosphere, thus, the efforts to avoid the possibilities of dangerous levels of global warming become complicated. Firstly, emission trend of carbon emissions has been identified based on the yearly data from the World Bank as shown in Figure 5-1.

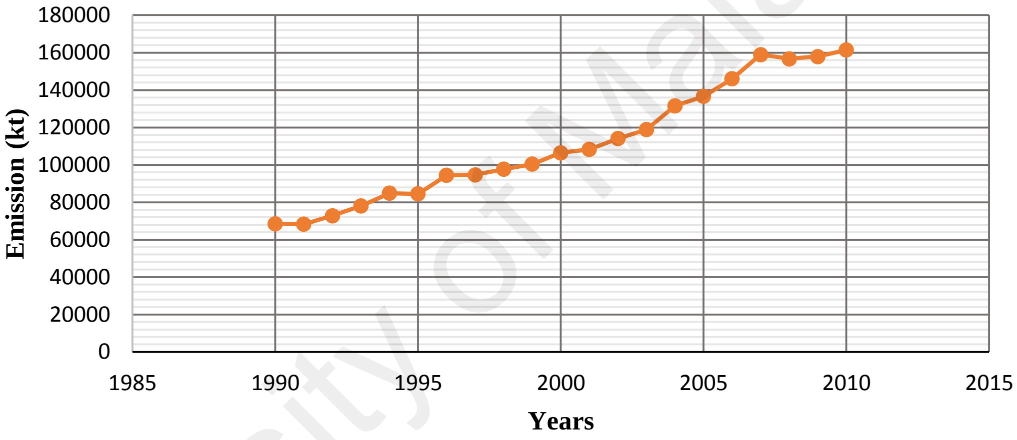

Figure 5-1 Emission Trend for Pakistan

Using the growth rate, obtained from the trend data we estimated emission values, for each time segment via emission growth model of the World Bank. Figure 5-2 represent the cumulative emission for each time segment, which clearly shows unrestrained emissions growth in each time segment.

It has been identified in various recent studies that cumulative CO_2 emissions and global mean temperature, are linearly linked. For example Zickfeld et al. (2009) claimed that perpetual CO_2 emissions cause global warming. In the South Asian region, Pakistan experiences the hottest and driest climatic condition. Temperature changes are also higher than the global mean; however, variations can be seen across the country.

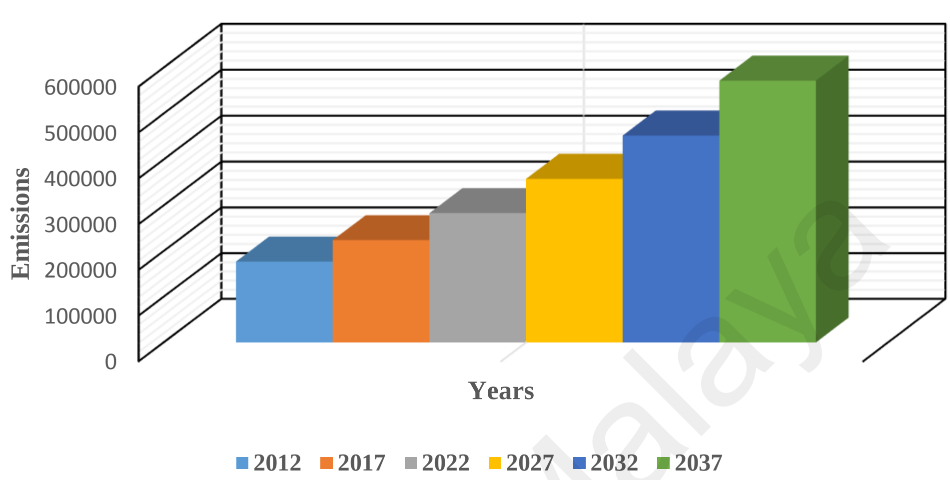

Figure 5-2 Emission Projection

Figure 5-3 shows the distribution of temperature data over the entire 20th century. The trend shows a mixed picture of temperature condition; however, overall it gives a rising image.

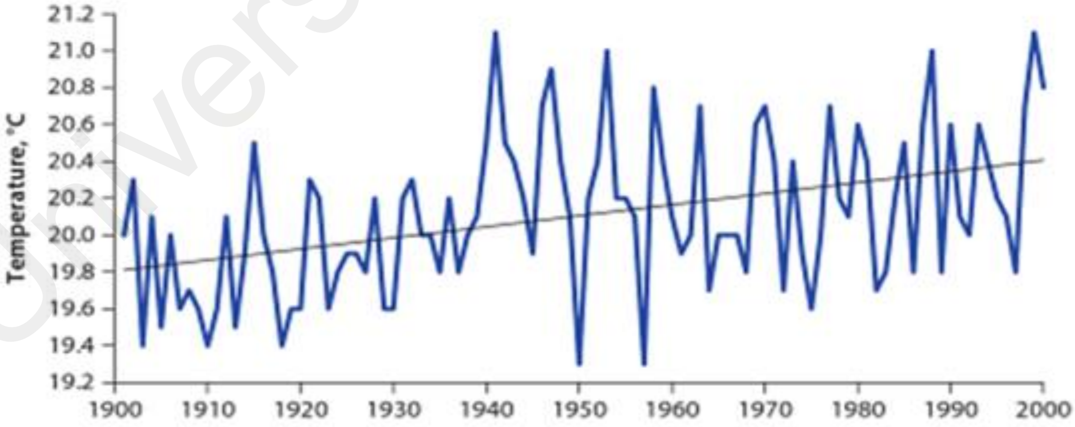

Figure 5-3 Temperature data for Pakistan 1900-2000

From the temperature trend, it can be inferred that in the year 2012 temperature has increased to 0.73°C compared to 1900. Figure 5-4 shows future temperature projections for Pakistan using 2012 as base year temperature. The temperature projection indicates that temperature increase for Pakistan is beyond the bounds of IPCC prescribed threshold limits. Such unprecedented temperature changes are alarming because it will lead to frequent and severe disaster like droughts, floods and storms in short run, while in long run, it will change rainfall patterns, degrade ecosystem, reduced biodiversity and increase sea levels (Annamalai et al., 2007).

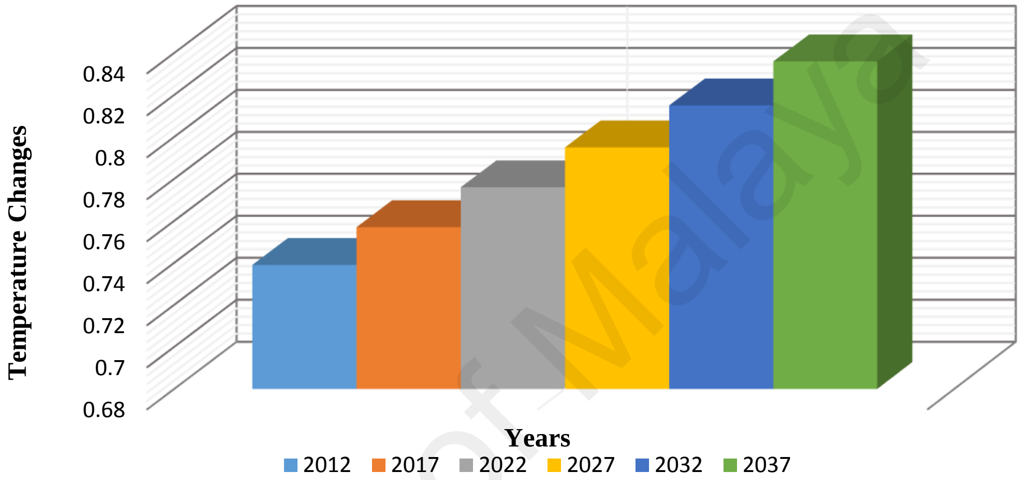

Figure 5-4 Temperature Projections across Time Segments

In order to analyze the linkage between climate change and monetary damages to the economy, first simulation under CI scenario has been conducted. Since this scenario considers zero level of technical change; hence it is inferred that we ignore any public or private policy to combat climate change effects. Additionally, compensation cost for technical change actions also considers zero.

In this study, damages estimation is carried out by adopting the spirit of top down and bottom up approach collectively; by using top-down approach, damage estimates for the base year are calculated, while following bottom-up approach, we provided some meaningful information to forecast damages in all time segments (Nordhaus, 1991; Ramanathan & Carmichael, 2008).

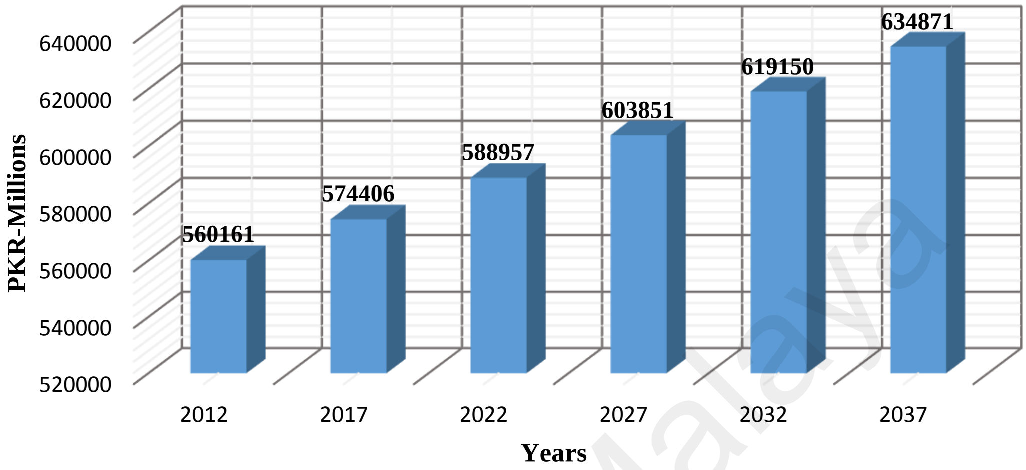

Figure 5-5 Gross Damages (CI Scenario)

Figure 5-5 represents climate damage costs on the present economy which is in equilibrium. The values indicate that frenzied increase in the projected temperature and emission values coupled with continuous economic activities will increase the gross damage over time. Each time segment presents different level of gross damages due to continuous changes in temperature, emissions, and economic growth. The results are significant in each time segment because we adopted downscaled DICE model parameters in simulation, which is an efficient estimation technique over the other methods (Nordhaus, 1994). Figure 5-5 also established that changing rate of gross damage is anticipated to increase over time, because of increasing disposition of temperature and carbon emissions. The damages have been changing over time, because the size and composition of the future economy, on which climate shows its impact, will not remain the same. Therefore, to compare the damages in each time segment, we estimated the projected real gross domestic product for Pakistan with the same time fragments as shown in Figure 5-6.

The overall gross damages are PKR[30] 560 Billion in national currency unit[31] which is 5.81 per cent of the country’s real GDP. The damages show an increasing trend, across all time segments, and raised up by 11.76 per cent from the base year, and reached to PKR 634 Billion in 2037. The damages experienced by the Pakistan economy are unprecedented as the fall way above the global average, which shows the extended exposure of Pakistan economy for climate catastrophes.

The economically detrimental impacts of climate change will be widely spread, and encapsulate the diverse sectors like agriculture, livestock, forest and fisheries (GoP,

Figure 5-6 Estimated Real GDP (CI Scenario)

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[30] 1USD = 95.8 PKR

[31] The national currency unit for Pakistan is PKR, hereon all the estimations are done in the same currency.

2010). The agricultural sector is highly susceptible to whims of nature and extremely vulnerable to climate change. Therefore, this sector will bear losses by the reduction in crop productivity and livestock production, etc. In either case, the country would face a decline in agriculture GDP, due to climate change.

In view of the dominant role of agricultural impacts, it is worth taking a closer look at this category. We model agricultural impacts as the sum of two effects; first, the negative impact in agriculture is entirely due to CO_2 emissions, second is the effects of temperature increase. Gross damage equation is modeled as a function of output. Therefore, gross damages are calculated for each time period as shown in the Figure 5-5. Thus, the simple way to eliminate the agriculture-specific damages is to subtract the industrial and services sector damages from the total. As a result, it will provide an increasingly reliable estimate of agricultural impacts as shown in the Figure 5-7.

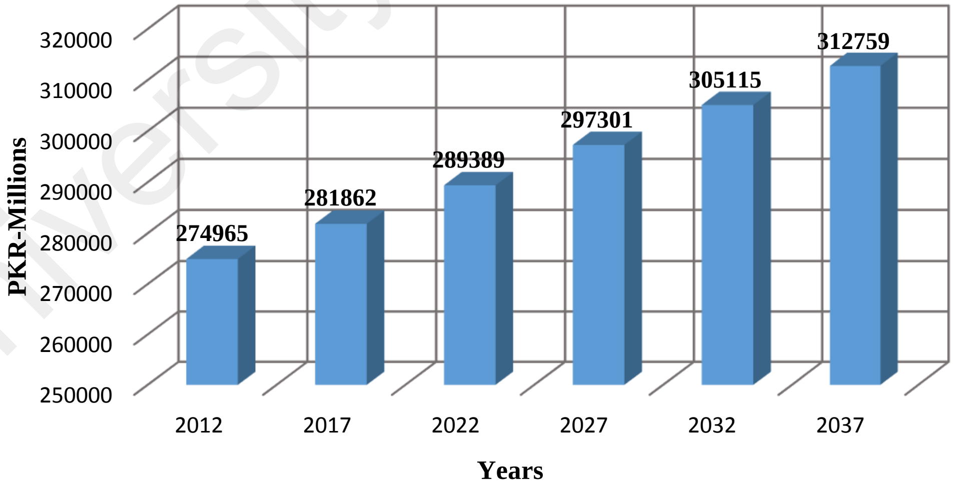

Figure 5-7 Agricultural Damages (CI Scenario)

Figure 5-7 demonstrates the total macroeconomic effects of climate change constraints on agricultural production. Climate change in terms of an exogenous shock to agricultural production cause the reduction in the real GDP at the rate of 2.85 per cent. The monetary value of GDP losses is PKR-274 Billions. Generally, the results show that aggregate economic effects of climate change on agriculture are negative; however, the percentage change reduction in GDP decrease over time (2.85 per cent in 2012 to 2.79 in 2037) as shown in the Figure 5-8. The reason for decreasing losses over time is decreased in the contribution of agricultural to the national GDP.

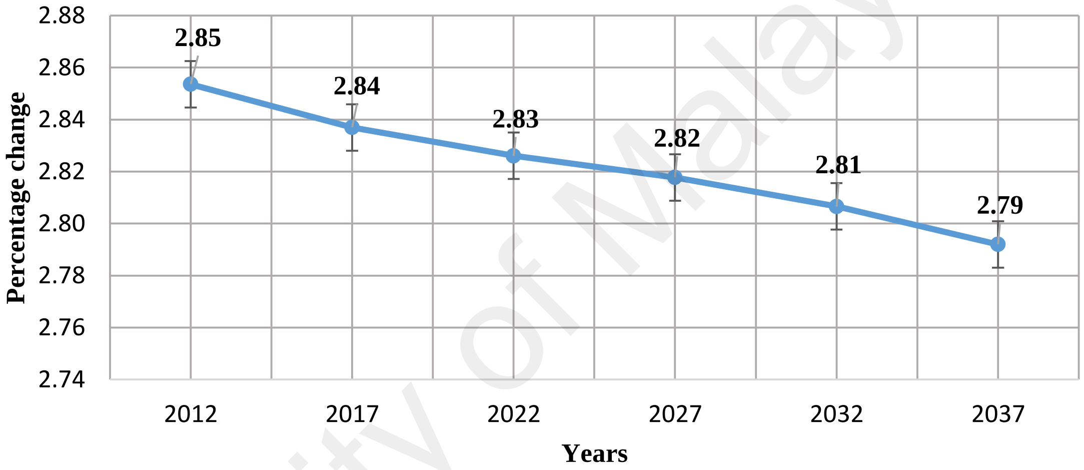

Figure 5-8 Agricultural Damages (Percentage of GDP)

It should be noted that if the monetary loss in the agricultural sector is analyzed and compared with total economic loss; agricultural sector losses increased by 12.08 per cent, which is 0.68 per cent higher than overall damages. The reason for the higher losses is the changes in resource allocation for the agricultural sector, due to the vulnerability of agricultural production inputs.

5.5 Sectoral Impacts

As described earlier that negative quotas of climate change on the agricultural sector are higher than overall effects on the combined economy. These impacts are shown in terms of sector specific effects as well in the Table 5-2. The results from the sectoral output highlight the fact that output for all the agricultural sectors, wheat, rice, sugarcane, livestock, and cotton etc. decreased substantially. These results were expected and can be explained by output effects resulting from climate change.

Table 5-2 Sectoral Agricultural Damages (CI Scenario)

Sectors	2012	2017	2022	2027	2032	2037
Rice	9832.7	10277.6	10678.9	11067.2	11500.1	11986.1
Wheat	26283.7	26900.3	27559.7	28247.1	28935.5	29621.3
Cotton	14359.6	14783.0	15216.2	15660.0	16115.4	16582.2
Sugar Cane	13111.7	13494.5	13903.7	14330.6	14756.4	15177.0
Tobacco	5643.2	5787.4	5961.3	6150.9	6327.5	6485.9
Other Crops	24858.9	25491.1	26155.9	26844.5	27540.3	28241.2
Pulses/Gram	10282.2	10583.5	10898.6	11224.3	11554.0	11886.4
Potato	10253.3	10549.9	10864.6	11191.9	11520.1	11847.0
Fruits	13939.7	14303.7	14698.8	15113.3	15523.8	15926.6
Vegetable	11469.2	11783.7	12121.4	12474.1	12825.5	13173.1
Oil Seed	11360.4	11642.6	11992.4	12377.0	12730.6	13042.5
Others	10671.4	10894.9	11215.9	11584.1	11900.3	12149.5
Livestock	87821.9	89680.6	91700.8	93819.7	95924.4	98002.1
Forestry	13686.2	14000.8	14394.7	14829.2	15227.0	15575.7
Fisheries	11390.7	11688.1	12025.9	12386.4	12733.9	13062.6

Note: unit of measurement is PKR

By looking into the results for sectoral damages, it is clear that the output reduces due to the constraints of climate change across all sectors. Another important feature is that all sectors witness decrease in output unanimously. The sector specific output under CI scenario is shown in Table 5-3.

Table 5-3 Sectoral Agricultural Output (CI Scenario)

Sectors	2012	2017	2022	2027	2032	2037
Rice	268812	280976	291948	302564	314402	327689
Wheat	718606	735464	753491	772287	791107	809860
Cotton	392583	404159	416003	428139	440590	453352
Sugar Cane	358464	368932	380117	391791	403433	414932
Tobacco	154264	158209	162963	168147	172975	177306
Other crops	679648	696935	715111	733937	752963	772126
Pulses/gram	281101	289341	297955	306861	315874	324962
Potato	280312	288421	297025	305974	314947	323886
Fruits	381102	391054	401857	413190	424414	435427
Vegetable	313556	322155	331387	341031	350640	360142
Oil Seed	310581	318296	327861	338377	348043	356571
Others	291743	297853	306629	316698	325343	332156
Livestock	2401145	2451965	2507199	2565133	2622677	2679485
Forestry	374172	382773	393543	405424	416299	425834
Fisheries	311410	319542	328778	338635	348135	357122

Note: unit of measurement is PKR

Comparing the results of output with damages, the simulation shows that climate change reduces the average production of agricultural commodities by 3.65 per cent. The results indicate that the distribution of damages varies across all the sectors of agriculture; while most climate-vulnerable sectors witness highest damages.

The sectoral damages as a percentage of GDP are shown in Figure 5-8, which shows the burdensome effects of climate damages on all the sectors. However, livestock, wheat, and other crops would suffer damages 0.91, 0.27, and 0.26 per cent of GDP respectively. In contrast, the range of economic damages for the rest of the sectors lies in-between 0.10 per cent to 0.15 per cent of GDP. The results suggest that there is a very large cross-sectoral distributional issue associated with climate change impacts. Moreover, it is clear from the results that climate change has a large impact on the overall agricultural sector. Specifically, simulated results show that future climate change lead to larger overall net damages.

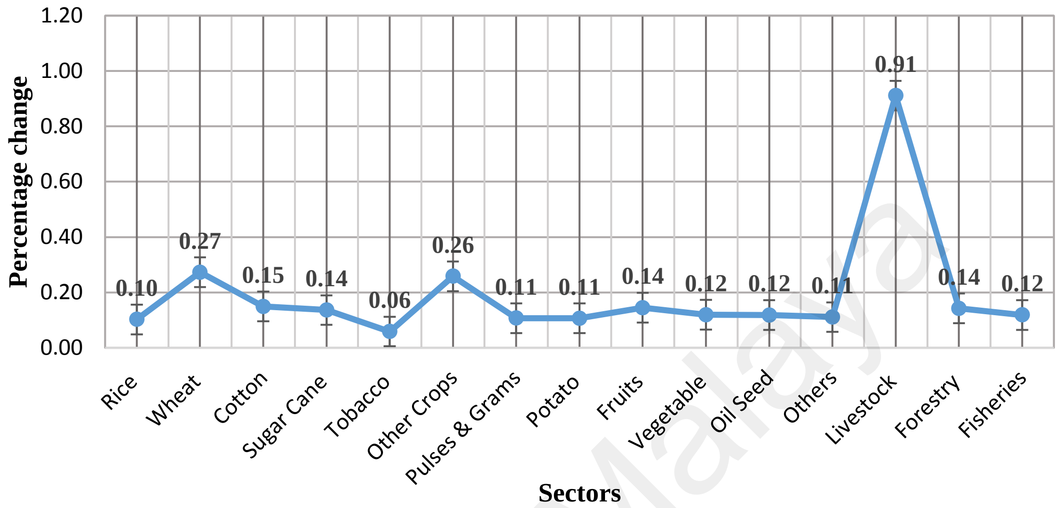

Figure 5-9 Sectoral Losses as Percentage of GDP (CI Scenario)

5.6 Discussion

The results analyzed in the previous section are interesting as the model generated outcomes that highlight the vulnerability of Pakistan economy to climate change, in general, and agriculture sector specifically. Overall most of the climate change impacts/policy studies are either global or regional in scope (Christensen et al., 2007; Jones et al., 1995; Meehl et al., 2007; Nobre et al., 1991; Parmesan & Yohe, 2003; Xuejie et al., 2001). However, the impacts and the costs of the climate change measures cannot be optimally determined on a global basis, as the impact will vary from region to region, between countries or even within a country (Hannah et al., 2007). The impact would be particularly severe in tropical areas, which mainly consists of developing countries, including Pakistan.

In Pakistan, climate change raises concerns with its tremendous social, environmental, and economic impacts; the impacts of the climate change, can be felt differently in each sector of an economy. The findings suggest that the agricultural sector of

Pakistan in highly exposed to climate change. The outcomes are appealing as they reveal the importance of climate change on the production of agricultural commodities. There was ample evidence that CO_2 emissions and temperature changes have been violating the 2010 Cancún Agreements[32]; in which the UNFCCC countries recommended a strong reduction of emissions for achieving global temperature below 2°C relative to pre-industrial levels. Furthermore, the temperature projection shows higher temperature changes in the coming decades. As a matter of fact, there was a pronounced increase in agricultural damages, which cause real GDP to reduce.

The monetary losses of GDP due to climate change were higher for Pakistan, as compared to the global average. Early studies with the country and a global perspective have suggested much lesser damages; for example Fankhauser (1994) show gross damages for the USA will be 1.2 per cent and 1.4 per cent in the world. While, Allen et al. (2009) indicate, global economic losses would be 1.9 per cent of the global GDP. The reduction in GDP typically associated with consumption and expenditure behaviors. The gross damages in the case of Pakistan are higher than the global average. Notwithstanding the simulated results are close with the findings of (Nordhaus, 2007).[33] However, Nordhaus (2008) criticized Stern (2007) findings by arguing that it violates the conventional climate modelling approaches, by lowering the time discount value, which accents future climate damages.

The reasons behind higher climate damages are manifold, (1) Pakistan is located in the South Asian region where impact of climate change are always negative (Fankhauser et al., 1997) (2) the natural resources in the ecosystems of Pakistan are delicately balanced, and face numerous challenges of changing climate, because 2°C rise in global mean temperature (from 1990 level) is considered as ‘‘dangerous climate change’’ for South Asia and Pakistan (Hussain & Mudasser, 2007) , (3), according to Maplecroft’s index of vulnerability to climate

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[32] Climate Analytics, Telegrafenberg A26, 14412 Potsdam (Wang et al., 2009).

[33] Stern estimates show that damages would be 5 percent of the world output, while in a broader case it would be 20 percent.

change, Pakistan ranks at 16th position out of 170 nations of the world, and (4) recently, the Pakistan Ministry of Climate Change launched a report in collabouration with the United Nations Development Programme, which placed Pakistan on the 3rd amongst the 10 most vulnerable countries to climate change.

The findings generally corroborate with the findings of (Ahmed et al., 2015; Rahman et al., 2014). Several major points emerge from the results. Climate change will exert negative effects on simulated agricultural production and subsequently crop yield will decrease. Climate change was found to increase disparities in cereal productions, where overall production shows sustainable declines in the long-run. Research suggests that adverse climate change reduces yield and productivity of agriculture by increasing the stress of weather inputs, and the exposure to vulnerabilities of climate extremes (Lomborg, 2010; Mendelsohn, 2006; Nordhaus, 2007; Tol & Yohe, 2006).

It is deemed that livestock sector generally shows better resilience in adopting climate changes relative to crops. The physiological system of animals allows them to adapt to extreme climate, due to the intense degree of behavioral expressions as compared to crops (Bryan et al., 2013; Kurukulasuriya & Rosenthal, 2013). Quite surprisingly, in the case of Pakistan, it is the most affected agricultural sub-sector despite its contribution to the national economy.[34] Climate change has far-reaching consequences for dairy, meat, and wool production. It is, therefore, erroneous to assume a homogenous impact of climate change across the globe. Climate change impacts grassland and rangeland productivity, while heat catastrophe reduces the feed intake of animals and results in poor growth performance (Thornton et al., 2009).

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[34] Livestock is one of the major sectors of the economy, accounting for 55.9 percent of agriculture earnings and 11.8 percent of GDP. It employs 35 million people and produces almost $500 million of products.

The broader effects of the conspicuous damages of climate change on the agricultural sector also need to be accounted for. As a majority of subsistence farmers are engaged in this sector, they will bear the direct losses due to reductions in crop yield and livestock health. This will intensify rural poverty by undermining the socio-economic condition of the rural masses. Additional costs will also be incurred through increases in government expenditure. Tackling losses and damages involve two aspects: first, decreasing avoidable losses and damages by reducing carbon emissions (mitigation) and averting climate change impacts (adaptation and risk reduction); and second, addressing unavoidable losses and damages through risk transfer strategies such as insurance, and risk retention mechanisms (for instance, contingency funds and social safety nets).

5.7 Summary

This chapter formulates the answers to the first two research questions. An integrated assessment model is used to empirically analyze the effect of climate change on agricultural production. The first section of the chapter discussed the course of proceeding with the scenario formulation and simulations. It describes the different scenarios and their underlying assumptions. The subsequent section of the chapter empirically modeled climatic change related impacts taking account of changes in temperature, carbon cycle, carbon emissions, climatic damage, and other related global warming factors up to the year 2037 with several breakdowns. By and large the analysis follows the recommendations of Stern (2007) and Nordhaus (2008), but the values of parameters and variables are downscaled to capture Pakistan's conditions.

Although the results are quite similar with some of the early work done but the results of climate damages are quite higher than global averages. For each time segment, we have found different damages depending on continued temperature change, emissions, economic growth, population growth, and so on. Our findings are significantly based on the fact that recent years have seen frequently climate catastrophes that are unprecedented in the history of the country since the impacts of climate change can be felt differently in each sector of an economy. However, the agricultural sector has been considered most vulnerable to climate damages as its production has a direct dependency on suitable climatic conditions. Among the downstream agriculture sectors, results reveal that livestock is the most vulnerable to climate change followed by wheat; however, tobacco crop proves to be most resilient to climate damages.

The last part of the chapter encapsulated the discussion on the regional and global difference of climate damages to Pakistan. Though the results showed considerable consensus with previous studies, but overall damages are utterly higher than the global average. Primarily, the arid geographical location of Pakistan and higher intensity of extreme weather events are responsible for higher damages. Moreover, noticeable heterogeneity exists in the sectoral damages, for example, the livestock sector, have the highest damages due to its greater share in the economy and dependence on other agricultural outputs. The chapter ended with the suggestion based on the results that avoidable losses and damages can be condensed by reducing carbon emissions, while risk transferring strategies can address unavoidable losses.

CHAPTER 6: TECHNICAL CHANGE AND CLIMATE DAMAGES

6.1 Introduction

This chapter tests the potential of technical change to redress climate damages. The rationale to test this is based on the arguments that in the case of a developing country technical change has economically moderate climate effects than adaptation and mitigation strategies. In this context, the aim of this chapter is to obtain an optimal level of Hicks's technical change that can redress climate damages from the agricultural sector. This will provide guidelines to the stakeholder when devising climate change policies for the country and agriculture sector. The chapter summarizes and presents the results of the TC scenario simulations.

The analysis is shown in four major parts. The first part briefly discusses the results related to the economic damages under climate change conditions and real GDP. In the second part, the cost associated with the optimal level of technical change is obtained. Similarly, in the third part climate damages to agriculture sector under TC scenario are calculated. Moreover, the damages are segregated into sector specific levels. The last part of results shows the cost of technical change actions at the sectoral level, it also shows the trend of technical change cost as a percentage of GDP. The final section of this chapter brings into discussion the results of the TC scenario.

6.2 Hicks's Neutral Technical Change and Climate Damage

The role of technical change becomes important while considering the solution of long-term environmental problems such as climate change. Nonetheless, technical change is treated as exogenous in most of the economic models for pure economic development and it can be used for climate change and related concerns in a similar fashion since technological innovation is the key to intensifying the productivity of further stage. Subsequently, policies formulated to combat climate change are likely to have a large impact on the pace and direction of technological change; hence, contemporary models miss the important link between policy and innovation.[35]

One of the most complex and salient questions remaining in climate modelling is the appropriate treatment of technical change. In this context, technical change can be understood as the increase in outputs with a given level of inputs. There are several different ways that climate policy modelers have incorporated technical change, even when it is only a function of time. Due to the neutral features of Hicks's technical change,[36] this study assumes it as a better[37] option for Pakistan. Nevertheless, other options like adaptation and mitigation are also available, but due to technical and economic considerations of the country like Pakistan they are not feasible.

6.3 Model Adjustments and Results

As described before, DICE is a dynamic growth model of the global economy that includes links between economic activity, carbon emissions, and the climate (Nordhaus, 2008). Since our focus is on Pakistan we downscaled the climate parameter of the model to fit in Pakistan's context. Furthermore, some modifications are done in the production function to accommodate Hicks's neutral technological change.

The production function of the model provides the linkage between activity levels as described in the production functions Equation below:

$$QA_a = \sigma_a \prod F_a . QF_f^{\propto f} \qquad 6\text{-}1$$

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[35] See (Popp, 2004).

[36] The notion of neutral technical change was first introduced by Hicks. It further illustrates the basic form of intangible technical progress in which neutrality features shifts production function over time by a uniform upward displacement. Additionally, the value of Hicks's range from 0 to 1, where 0 indicate no technical change while 1 represent 100% technical change.

[37] It is considered a better option among others because Hicks's technical change decreases relative prices of the factors of production that is itself a spur to invention of a particular kind. Further, Hicks's technical change is directed to economizing the use of a factor which has become relatively expensive.

The production efficiency will increase as a result of Hicks's neutral technical change without any alteration of input combinations. Overall technological progress comes through changes in total factor productivity. Furthermore, it will help to overturn the damages caused by climate change in agricultural production. Therefore, Equation 6-2 provides the framework through which we can incorporate Hicks's neutral technical change in the model.

$$QAC_a = \left\{ \sigma_a \prod F_a . QF_f^{(\propto f-1)} \right\} * \left\{ 1 + \gamma_f \right\} \qquad 6\text{-}2$$

Where, γ is Hicks's neutral technical change and its value varies between 0 and 1. The values are generated following the Bardhan et al. (1971) methodology[38]. The zero value indicated that there is no TC while one indicated cent percent TC. Hence optimal technical change value is calculated by lowering the marginal damages using the marginal concept of benefit and damage in our analysis, in that case following trial and error method several simulations are carried out to reach optimum level of TC. Therefore, based on the time segments we simulate the results by imposing Hicks's neutral technical change as an optimal strategy against CI scenarios.

6.4 Findings

The previous chapter shows the results of the monetary damages of climate change to the overall economy in general, and agricultural sector in particular. The overall monetary losses were estimated to be PKR 560 Billion in the national currency unit[39] which is 5.81 per cent of the country's real GDP. These monetary costs represent reference based on CI scenario simulation that only considers the impacts of climate change without any response action. However, the TC simulation analyzes the impacts of

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[38] For details please see also (Klump et al., 2007).

[39] The national currency unit for Pakistan is PKR, hereon all the estimations are done in the same currency.

response action in the form of introducing autonomous Hicks's neutral technical change variable.[40] This simulation expedites the effects of technical change in redressing the economic damages of climate change. Consequently, the percentage change in neutral technical change is considered to discover the magnitude and direction of change in climate damages.

To begin with damages estimated under TC scenario Figure 6-1 shows climate damages as a function of the time. The introduction of Hicks's neutral technical change leads to a noticeable decrease in monetary damages. Moreover, the value of Hicks's variable that generates efficient results is 0.013 i.e. 1.3 per cent. This is the level of technical change required to balance climate damages from the economy. In fact, additional Hicks's technical change (optimal) not only reduces climate damages but also scales up the entire economy. It can also be inferred from the results that technical change not only reduces climate damages but it also increased total factor productivity (TFP) significantly.

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[40] Hicks variable varies (γ) between 1 and 0.

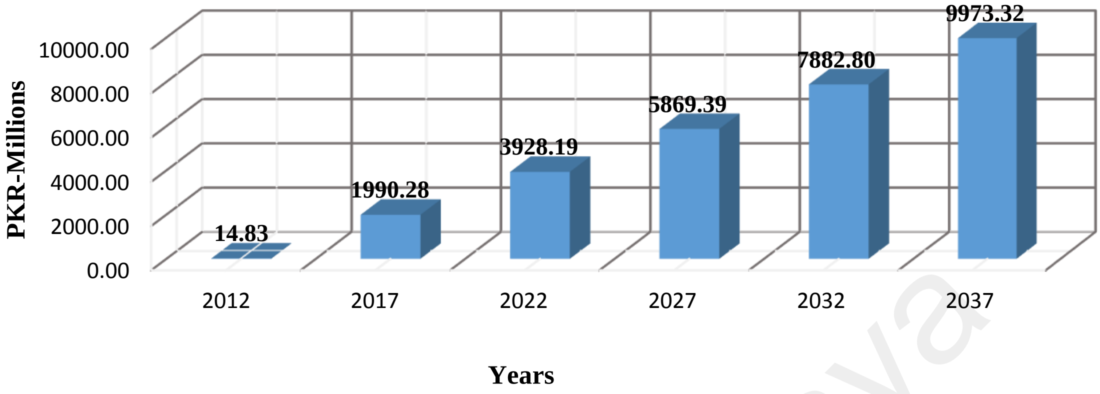

Figure 6-1 Economic Damages (TC Scenario)

The comparative analysis of Figure 5-5 and 6-1 shows that climate damages reduced from PKR 560 Billion to 14.8 Million. This shows 99 per cent of the damages recovery in the base year, with the optimal level of Hicks's technical change. This tendency has been known as rebound effect as described by Grimaud et al. (2011). However, the rebounded effect in environmental analysis is considerably more significant than the findings of Grimaud et al. (2011) are, because technical change generates efficiency in resource consumption, while at the same time emissions are reduced.

As illustrated in Figure 6-1 the effects of climate change have been reduced in all time periods under the TC scenario. Nevertheless, natural resources are still significantly affected by climate change as damage in the TC scenario increase over time. However, the evaluation of the technical change during each period shows that the effects of technical change actions remain economically significant.

In line with the reduction in climate damages, noticeable upturns in the real GDP under TC scenario is also visible as shown in Figure 6-2. Coherently, with the percentage change in Hicks's variable, total production level is increased by 2.13 per cent. The higher real GDP highlights the effectiveness of the Hicks's neutral technical change in the economy. In comparison with CI scenario, real GDP increased by 2.13 per cent, with the incorporation of Hicks's technical change. The results for this increase in real GDP identify two reasons. Firstly, it is due to increase in the production efficiency,[41] and secondly, higher productive efficiency ultimately puts cuts on the CO_2 emissions, which moderate climate change.

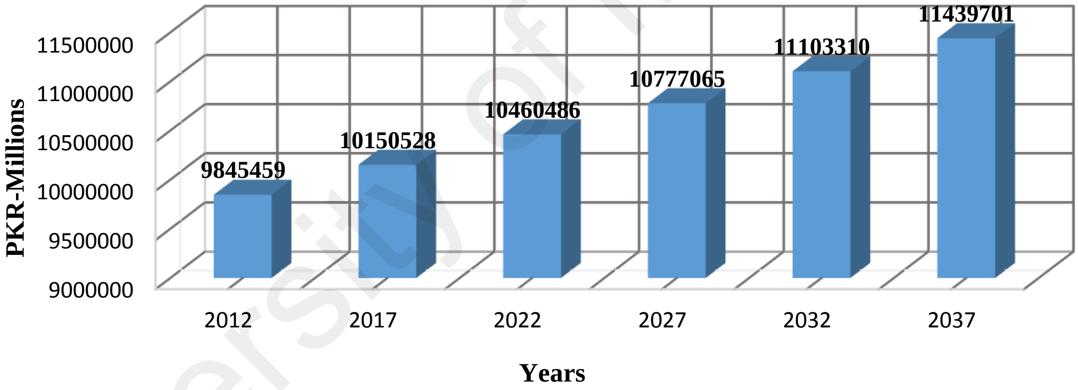

Figure 6-2 Real GDP (TC Scenario)

In term of the results for damages and real GDP, the decrease in damages under TC scenario, and an increase in the GDP was the outcome for the investment for increasing total factor productivity.[42] The cost of such investment under the TC scenario

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[41] Output increased per unit of input, due to technical change.

[42] Changes in Total factor productivity shows Hicks's neutral technical change.

is shown in Figure 6-3. The results depict that in the case of Hicks's neutral technical change, the cost for the optimal level of additional Hicks's neutral technical change will be PKR-209 billion in the base year.

It is also important to note that magnitude of the cost required to reduce the climate damages increases over time. However, technical change will raise the production enough to offset the negative impacts of climate change, and generate welfare gains. It can be seen that cost for financing technical change reduces from 2.13 per cent in the base year to 2.07 per cent in 2037.

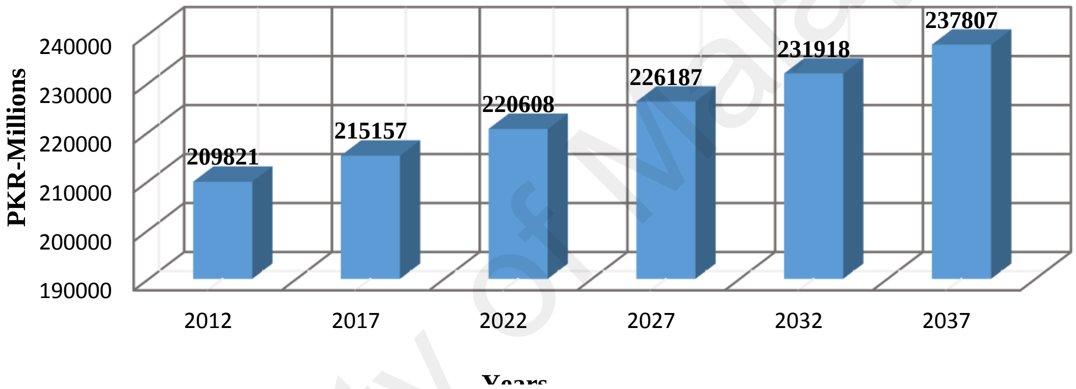

Figure 6-3 Cost of Technical Change (TC Scenario)

The declining trend of percentage cost has its implications. Firstly, it shows that the economy as a whole is well-off due to technical change actions; for example in the base year, the economy of Pakistan will gain PKR-350 billion with the efficient allocation of existing resources. Secondly, it also advocates the fact that early action accounts for higher cost while during later stages it will reduce comparatively. In addition, it affirms the fact that Hicks's neutral technical change increases the efficiency of production over time which escalates GDP. It is also important to note that, the cost of technical changes are much less than the incurred climate damages. For example, in the base year, the cost of technical changes is 37.5 per cent of total damages to the economy. This means that with the introduction of technical change 62.5 per cent of monetary damages can be recovered.

The other encouraging effect of introducing Hicks's neutral technical change variable can be seen from the results for aggregate damages of agriculture. The outcome for the agricultural sector is more interesting when considering it under TC simulation.

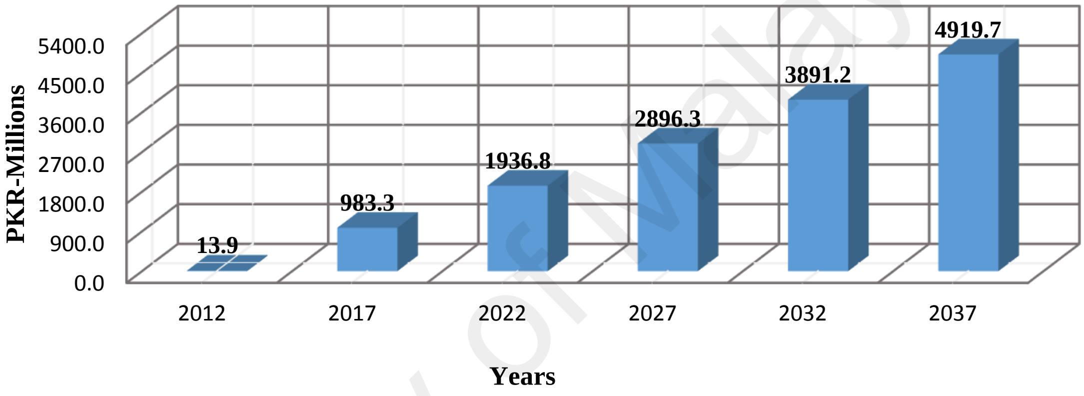

Figure 6-4 Gross Agriculture Sector Damages (TC Scenario)

The reported agricultural damages were PKR-274 billion in base year as shown in CI scenario (see Figure 5-7). However, under the TC scenario, damages reduced to PKR 13.94 million as shown in Figure 6-4. This shows that Hicks's technical change increases the efficiency of agricultural inputs that reduce climate damages by improving productivity. Consequently, from the production side, total production will increase as a result of higher input efficiency.

Additionally, the sectoral decomposition of damages is presented in Table 6-1. The sector-specific results also confirmed that imposition of technical change reduced significant damages in each sector. It is also important to note that damages for the livestock sector are lowest among all sectors at an optimum level of technical change. Since production of the livestock sector depends on other agricultural sectors, the accumulated damages in livestock are reduced by the reduction in damages of all the sectors.

Table 6-1 Sectoral Specific Damages (TC Scenario)

Sectors	2012	2017	2022	2027	2032	2037
Rice	0.96	36.30	71.91	108.25	147.09	188.96
Wheat	0.90	93.41	184.02	274.76	368.60	465.53
Cotton	0.94	51.78	102.04	152.77	205.73	261.04
Sugar Cane	0.95	47.36	93.33	139.88	188.46	239.00
Tobacco	0.98	20.88	40.58	60.61	81.38	102.70
Other Crops	0.90	88.57	174.70	261.17	350.87	443.89
Pulses/Gram	0.96	37.36	73.37	109.78	147.78	187.40
Potato	0.96	37.24	73.15	109.46	147.34	186.78
Fruits	0.95	50.14	98.61	147.47	198.21	250.76
Vegetable	0.96	41.48	81.49	121.89	163.93	207.58
Oil Seed	0.96	40.99	80.64	120.95	162.72	205.53
Others	0.96	38.43	75.48	113.26	152.18	191.52
Livestock	0.66	309.09	609.98	910.30	1219.66	1537.94
Forestry	0.95	49.10	96.59	144.72	194.44	245.26
Fisheries	0.96	41.15	80.86	121.04	162.77	205.84

Note: unit of measurement is PKR

Closer observation to the base year damages component as a percentage of total damages is shown in Figure 6-5. The results depict that tobacco contribute 7.02 per cent to the total damages which are the highest among all the sectors. Moreover, rice, potato, vegetables, and sugar cane contribute 6.90, 6.89, 6.86 and 6.81 per cent respectively. Another interesting result from implementing technical change is the lowest damage share of livestock among all the sectors. In CI it was highest, where inverse conditions can be seen for tobacco. The decrease in the percentage damages in livestock shows the positive effect of technical change across all the subsectors involved in the production of livestock. However, the higher damages in tobacco show that it has the lowest investment cost for technical change.

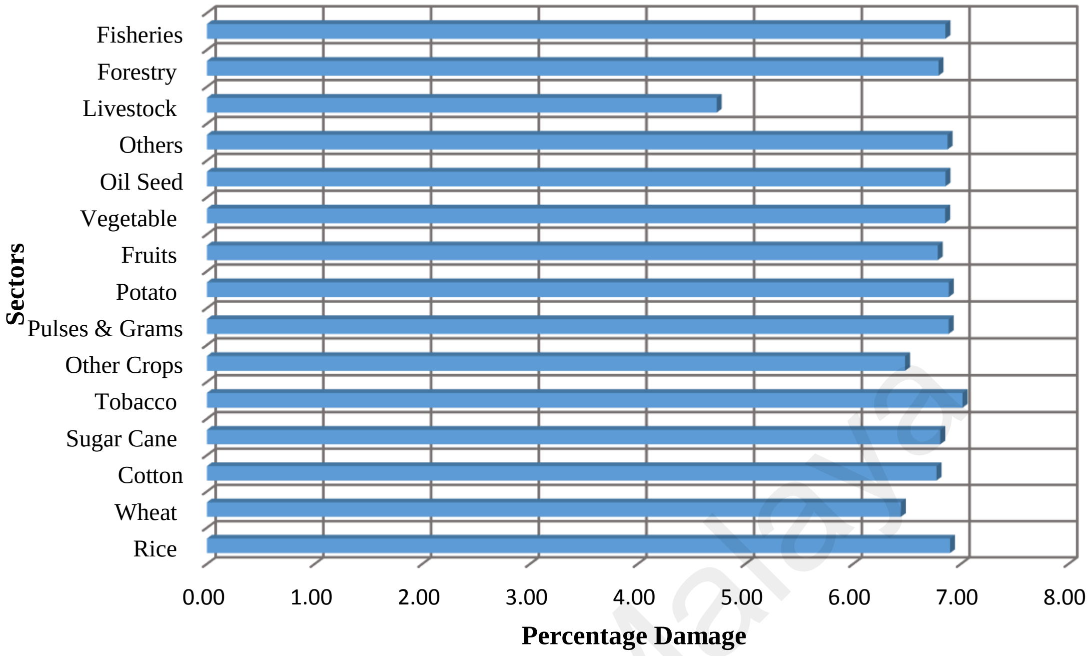

Figure 6-5 Percentage Sectoral Damages (TC Scenario)

The outcome for the cost at sectoral level confirmed this claim as shown in the Table 6-2. In terms of cost, shown in Table 6-2 livestock accumulated highest investment cost while tobacco shows the lowest cost of technical change. It is important to note that the cost for technical change investment is way below the monetary damages for each sector, which shows the effectiveness of the technical change in curbing climate damages at sectoral level. It also affirms the fact that with the escalation of efficiency in production process TFP of all the subsectors improves simultaneously.

Table 6-2 Sector Specific Cost of Technical Change

Sectors	2012	2017	2022	2027	2032	2037
Rice	3683	3849	4000	4145	4307	4489
Wheat	9845	10076	10323	10581	10838	11095
Cotton	5379	5537	5699	5866	6036	6211
Sugar Cane	4911	5054	5208	5368	5527	5685
Tobacco	2113	2168	2233	2304	2370	2429
Other Crops	9311	9548	9797	10055	10316	10578
Pulses/Gram	3851	3964	4082	4204	4328	4452
Potato	3840	3951	4069	4192	4315	4437
Fruits	5221	5358	5506	5661	5815	5965
Vegetable	4296	4414	4540	4672	4804	4934
Oil Seed	4255	4361	4492	4636	4768	4885
Others	3997	4081	4201	4339	4457	4551
Livestock	32896	33593	34349	35143	35931	36710
Forestry	5126	5244	5392	5554	5703	5834
Fisheries	4266	4378	4504	4639	4770	4893

Note: unit of measurement is PKR

The percentage variation in the cost of technical change is shown in Figure 6-6. A fundamental result of higher cost in livestock sector (31.94 per cent) is inevitable because it has higher damages outcomes (Table 5-2) compared to all other sectors. Moreover, other noticeable contributions are obtained from wheat (9.54 per cent) and other crops (9.04 per cent). The lowest share of the cost can be seen for tobacco (2.05 per cent) courtesy of lowest damages (Table 5-2). Consequently, under TC simulation results it shows the highest damage outcome due to lowest invest cost as shown in Table 6-1.

Similarly, the total cost of technical change involves curtailing the agricultural sector damages has been determined by subtracting industrial and service sector cost from the total cost. Figure 6-7 shows the results for the accumulated cost of technical change for the agricultural sector. In line with the total cost, agricultural sector costs have similar implications i.e. cost for agriculture is also 37.5 per cent of the monetary damage for all the sub-sectors of agriculture.

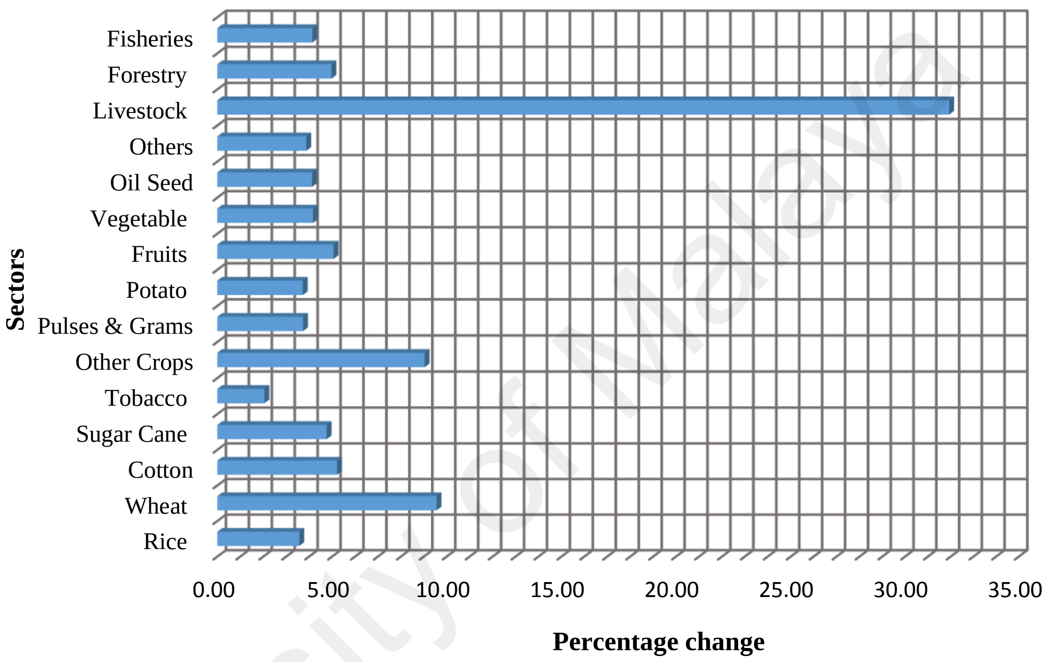

Figure 6-6 Percentage Sectoral Cost (TC Scenario)

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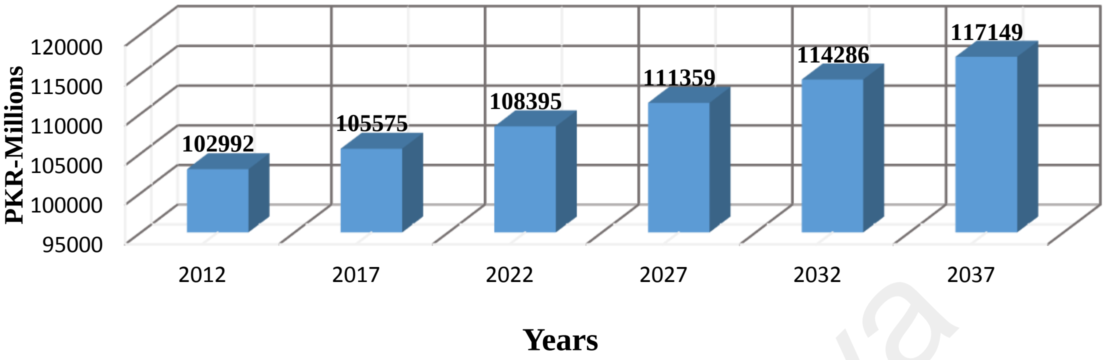

Figure 6-7 Cost for Agriculture (TC Scenario)

The investment cost of technical change action in the agricultural sector as a percentage of the respective real GDP is shown in Figure 6-8. The outcome of cost as a percentage of GDP confirms the claim that technical change has significant welfare effects. Moreover, the spillover effect of technical changes are positive and cost less as described by (Wolff, 1997). Consequently, the positive effects of technical change enhances agricultural production, which ultimately increases GDP, hence the percentage cost of technical change reduces over time as shown in Figure 6-8.

Thus, from the aforementioned results, it can be inferred that additional investment in technical change up to optimal level limits the effects of climate change on the agricultural sector effectively. Moreover, the additional Hicks's neutral technical change that would be optimal to generate lowest possible damages of climate change is 0.013 i.e. 1.3 per cent. This value is selected after running multiple simulations because it generates the possible outcomes that are consistent with economic theory.

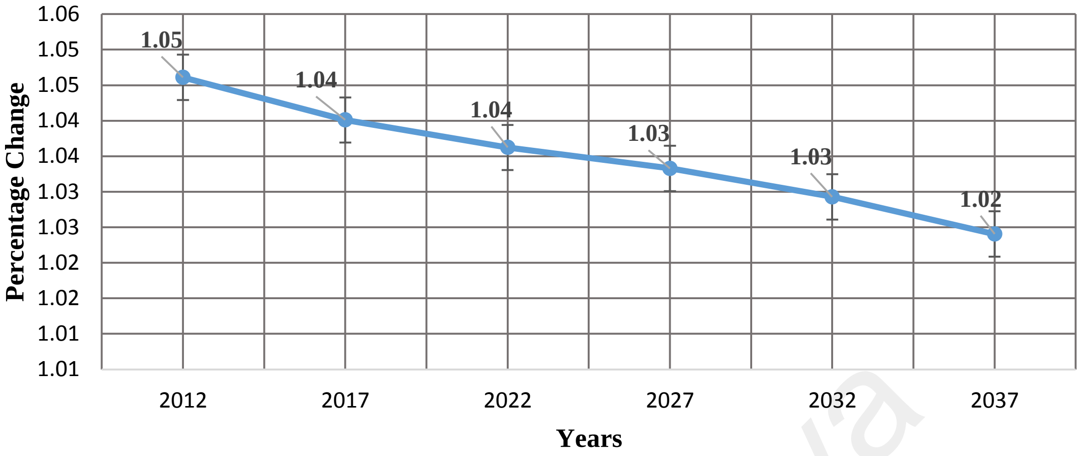

Figure 6-8 Technical Change Cost as Percentage of GDP

6.5 Discussion

The projected damages of climate change without any response policy were found to be 5.84 per cent of real GDP.[43] Damage estimates in Pakistan's case have been considered much higher as compared to global averages.[44] This paves the way for opting broad-range structural changes in economic activities that are of the utmost importance in addressing climate change vulnerabilities. Following a neo-classical growth view, capital accumulation eventually succumbs to diminishing returns, hence productivity growth entirely based on the exogenous technical progress. Therefore, technical change has been modeled as an exogenous variable, like a simple autonomous function of time.

As technical change is assumed to be exogenous, hence it represents Hicks's-neutral in the absence of any accumulating factors. Productivity changes are the natural outcome of the additional Hicks's technical change. The striking implication of the neo-classical model is that the productivity growth is driven entirely by growth in exogenous

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[43] The damages of climate change had been reported in chapter 5.

[44] Early studies with country and global perspective have suggested much lesser damages; for example Fankhauser (1994) show gross damages for USA will be 1.2% and 1.4% to the world. Allen et al. (2009) with the same approach indicate that the losses to the global economy would be 1.9% of the global GDP.

technical progress and it is independent of the structural parameter. In a condensed form, our results portray a positive significant influence of Hicks's neutral technical change on the economy, as well as on agriculture to redress the effects of climate change.

Technical change exhibits efficiency to curtail climate induce damages as illustrated from simulation results. These results are greatly consistent with the extensive empirical work. With reference to mitigation potential of technical change, empirical literature mentions that technical change has the potential to displace and expand the mitigation potential of existing technologies by reducing cost (Bosetti et al., 2009; Edenhofer et al., 2005; Gerlagh, 2008). In particular, according to Trabalka et al. (1986) technology offers potentials to overcome barriers for addressing climate change by improving efficiency in the production process. On the same note, Hall (1989) articulated that Hicks's-neutral technical change leaves marginal rate of substitution between inputs unaffected in production function framework, while improving the efficiency by higher investment expenditure in existing inputs.

The prominences of the simulation results are the identification of the optimal level of Hicks's technical change for Pakistan economy, efficient to amends effects of climate change. The optimal Hicks's neutral technical change has been estimated to be 1.3 per cent. This rate represents the required growth rate in TFP to yield diminishing climate damages. Our results are consistent with the empirical studies previously conducted, which shows that the current level of TFP is much lower than optimal for Pakistan. Starting with Martin and Mitra (2001) considered TFP as the prime determinant of growth, shows that TFP rate for developing countries, including Pakistan, lies between 0.62 to 0.92 per cent. Similarly, Baier et al. (2006) mentioned that the average TFP growth for Asia is 0.22 per cent. In a similar study Islam et al. (2008) found that average neutral technical change rate for South Asia is 0.48 per cent.

However, according to World Bank estimates total factor productivity in Pakistan, drastically decreased to 0.19 per cent in 2006, while reaching 0.86 per cent in 2012. Considering, the estimates of World Bank and the simulation results it can be seen that 0.44 per cent additional technical change will be optimal to generate efficient sustainable production across the entire economy to overcome climate-induced damages. In other words, it shows the rate at which production was taking place in a cost-effective and sustainable manner. It is also important to note that growth in the production process can be attained by using higher and higher level of inputs, which is not suitable in the long run (Krugman, 2000) because incremental output involves increasing doses of incremental inputs. Thus, the sustainable production growth necessitates faster growth in output than inputs. In this manner, the rate of Hicks's neutral technical change is an excellent indicator of the performance of any production system.

It is widely acknowledged in the literature that production of weather-dependent sectors, such as agriculture, is likely to be substantially affected by climate change (Antle et al., 2010). For instance, the productivity of rice and wheat in South Asia has reduced to -0.2 and 0.11 per cent in 2007 (Kumar et al., 2010). The brunt of the adverse economic impacts of climate change is seen in Pakistan agriculture sector as well, where agricultural production is climate sensitive and adaptive capacities are low. In the case of Pakistan, TFP had decreased for crops and livestock from 2.7 to 1.9 per cent during 1977 to 1988. However, during 1988 to 1997 it had increased from 2.7 to 4.2 per cent, while reduced to 0.82 per cent in 2012.

Simulation results show that, technical change shifts in the sectoral output, particularly for agriculture and its respective sub-sectors, which are driven by sharp changes in relative climate impacts. Moreover, the sector-specific results are in line with the findings of Ludena et al. (2007). They claim that average global rate of Hicks's technical change would be 1.13 per cent to redress climate damages in agriculture. Additionally, most of the world regions are likely to experience larger productivity gains in livestock than crops. Moreover, technical change will generate rapid rates of productivity growth in the crops sector of developing countries (Pakistan), which may be converging to the productivity level of developed nations.

It can be seen from the results that technical change can increase production well enough to redress climate damages in all agricultural sectors by escalating efficiency in the production process (Islam et al., 2008). Technical change cause improvements in production practices in a way that moves closer to the existing best practice, since in our simulation results, technical change represents TFP. The growth in agricultural productivity is both a necessary and a sufficient condition for redressing the effects of climate change, as shown in the simulation results. However, the slackness in investment on agricultural research and technical change is a matter of concern in the context of the threatening level of climate change impacts on Pakistan.

Correspondingly, model parameters project the investments in agriculture, which is used to estimate the cost of achieving a given change in TFP. The projected results indicated that in the case of overall economy the total investment cost for an optimal technical change is 2.13 per cent of GDP, where for agriculture this cost is 1.02 per cent of GDP. Although our model results are similar to previous studies, it is much lower than global findings. For example, Muller et al (2010) account for appropriate investments in new research needed to redress climate impacts in the agricultural sector. According to their findings to catch up 4 per cent agricultural growth rate 2.4 per cent of GDP needs to be invested in agricultural R&D. In a similar study Lobell et al. (2013) claimed that a 10 per cent increase in agricultural investment is assumed to result in a 3 per cent increase in TFP. These findings are in accordance with the early estimates of (Nelson et al., 2009).

In line with these findings, Place et al. (2007) claim that for harmonizing climate effects in agriculture investment in agricultural R&D are inevitable to enhance TFP.

In the case of Pakistan, the sources of growth in TFP to an optimal level in agriculture can be understood through TFP decomposition analysis. It is important to note that agriculture-related technical change can be divided into two components i.e. quality and quantity. The former represents the productivity improvement courtesy of technical change. Chand et al. (2012) found that public investment in research, extension, infrastructure, human capital, along with production strategies are important factors in boosting TFP. Moreover, public investment helps to break the seasonal barrier in crop production and to a larger context, it shifts the acreage of production also. Given that investments in agriculture have potential impacts on adaptation efforts, which equip farmers to build tolerant surroundings for combating adverse environmental conditions. In line with our findings Evenson (2003) also highlights the land saving effect of investments in the Green Revolution, while Stevenson et al. (2014) explored the effects of investment on yield increases of major crops.

The results reveal that crop productivity increases uniformly across all sub-sectors. The impacts of technical change can be assessed by looking into the production of agricultural commodities under technical change conditions. There are positive effects of technical change on the production of major crops.[45] The hallmark of technical change is the significant increase in the production in all agricultural sub-sectors; this satisfies Hicks-Kaldor Criterion (Hicks, 1939).[46] However, across the agricultural sub-sectors, the

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[45] Like, Cotton (Increased by 1.38%), Wheat (Increased by 1.36%), Rice (Increased by 1.32%) and Sugarcane (Increased by 1.29%).
[46] For a potential Pareto improvement to occur, the gainers from the change must be hypothetically able to compensate the losers and still be better off with costless redistribution. The change is potentially an improvement, since if the gainers actually did compensate the losers everyone would be better off.

increase in the production of livestock is important, since it is dependent on the other sub-sectors; it shows, indirectly, the cumulative effect of various production sectors.

Our results portrayed that Pakistan being a resource constraint economy needs to address the currently prevalent productivity gaps by investment in technical change. The optimal level of additional technical change has been matters of some importance because it leads to the level of investment required to increase the production efficiency. In this sense, investment broadly may be considered as any expenditure that provides productive payoffs in future. The often suggested measure for accelerating TFP growth is jacking up investment in infrastructural facilities and increasing input-use efficiency. Ironically, in the case of Pakistan, a declining trend in public investment in agriculture is evident which needed to be reversed. It is the only option to accelerate growth in TFP by increasing yield potential in both irrigated and rain-fed areas. Making headway in acquiring mobilization of investment in agricultural research has been convincingly justified in several studies (Alston et al., 2009; Fan, 2000; Pray & Fuglie, 2001). In line with that, extension work should be developed to disseminate the new practice of production. For example, an integrated approach of cropping pattern, which encourages greater efficiency in utilization of natural resources, ameliorating soil-related problems, incorporation of legumes in the cropping systems, and enhancing water-use efficiency.

Additionally, under constrained investment conditions technical change is more effective for curing the climate damages in the agricultural sector than mitigation and adaptation measures. In compliance with our results (VijayaVenkataRaman et al., 2012) reported that mitigation can retard the growth of developing countries like Pakistan, by putting limits on emissions. Similarly, Worrell et al. (2009) acknowledges that mitigation strategy demands the complete transformation of transport and energy production systems. The overwhelming body of empirical literature reporting the adaptation strategy has been proven effective only with a certain level of adaptive capacity (Brooks et al., 2005; Hinkel, 2011; Lindner et al., 2010) effective role of technical change, while addressing climate change effects on agriculture. Finally, adaptation is not cost effective in the case of Pakistan, which has a low level of literacy and weak institutional capabilities (Byatt et al., 2006) .

In addition to that, Hicks's neutral technical change reduces the tedious work of formalizing independent adaptation or mitigation policies for individual sectors. The optimal level of technical change reduces the damages across all the subsectors simultaneously. It can be seen that agricultural damages are significantly reduced with technical change, despite climate change. All crops show positive response to technical change. During each period, for most agricultural sub-sectors, the monetary significance of technical changes on production are obvious. Technical change improves productivity sufficiently to overcome climate damages.

6.6 Summary

This chapter begins with a simulating optimal level of technical change for an arid geographic country like Pakistan. While impacts of climate change are multiplying at a faster rate than ever, the compilations of an effective strategy to counter the threat of climate change are essential. However, considering the disproportionate effects of this threat, especially in developing countries like Pakistan that lie in climate hotspots, there is a dire need to prioritise the nature of state response. The combination of adaptation and mitigation policy is considered effective in terms of the reduction of climate change negative impacts; however, adaptation is expensive while mitigation has quantitative restrictions since it is a developing country and any restriction on CO_2 emission can reduce the economic productions.

In the proceeding sections we assessed that technical change (Hicks's assumption) is liable to reduce climate damages; for that reason, it is well identified and articulated. In the case of agriculture, cumulative losses of 2.75 per cent of the real GDP exist for Pakistan, which is then projected to increase to 14.25 per cent by 2037. However, the calculated costs of technical changes projected at 2.13 per cent of real GDP in the base year are expected to decrease over time due to spillover effects of technical change.

Thus, the study finds a cost-effective optimal level of technical change (1.3 per cent) that potentially reduces crop damages to a minimum possible level. It is not feasible to move beyond 1.3 per cent of technical change, because any further increase higher than that level, the costs of technical change will outweigh the reduction in crop damages, resulting in negative gains from technical change. One must, therefore, consider the mechanism by which technical change reduces the negative effects of climate change on agriculture. It is possible that it can sharply revert the climate damages by shifting the production function. Alternatively, it may be the case that the utilization of natural resources is optimized, as alternative technologies that are environment-friendly and efficient are commercialized. Hence, it can be concluded that optimal technical change is cost- effective because it satisfies the Hicks-Kaldor Criterion (Hicks, 1939). It can also play a dominant role in any long-term perspective of climate policy. As such, further work is needed to identify the processes through which technical change can be adopted in an efficient manner.

CHAPTER 7: ANALYSIS OF TECHNICAL CHANGE PERFORMANCE

7.1 Introduction

This chapter analyses the effect of technical change by comparing different scenario results. It explains the nature of agriculture production and the economy as a whole under climate and technical change conditions. The chapter begins with the comparison of agricultural production under different scenarios. After asserting the production difference, residual damages are compared and benefits of technical change at a sectoral level are identified. The final section of this chapter brings into discussion the results of the macroeconomic impacts of technical change by comparing real GDP, government expenditure, and consumption.

7.2 Production of Agricultural Commodities

To define the net effect of technical change on the economic output of agricultural commodities, the output for each sector under all the scenarios is compared. The detailed description of all the scenarios has already been ascertained in chapter 5. To carpet the monetary contribution of the entire agricultural sector production values of all agricultural subsectors have been accumulated. The accumulation will provide a yardstick to identify the benefits of technical change on agricultural production. Table 7-1 provides the estimated values of the entire agricultural production in different scenarios.

For the benchmark solution, climate change accounts for about 5 per cent decrease in the domestic agricultural output, which is the first potential feature of the results presented in Table 7-1. It is also important to note that climate impacts on other consumer commodities are smaller than agriculture. However, technical change escalates production of agriculture by 1.30 per cent with reference to CI scenario. Thus technical change redresses 3.69 per cent of climate damages; this indicates the effectiveness of technical change.

Table 7-1 Agricultural Output (Millions)

Scenarios	2012	2017	2022	2027	2032	2037
BL	7913178	8111678	8328302	8556009	8780906	9000918
CI	7517505	7706080	7911873	8128194	8341847	8550858
TC	7620497	7811656	8020268	8239553	8456132	8668007

Note: unit of measurement is PKR

Following that we reported sector specific effects of technical change on agricultural production. Table 7-2, 7-3, and 7-4 summarizes the sectoral level output under three scenarios. On one hand, simulation results advocate production losses in all downstream agricultural sectors due to climate change. On the other hand, it provides evidence that technical change redress losses in all sectors by increasing production.

Table 7-2 Production under BL Scenario

Sectors	2012	2017	2022	2027	2032	2037
Rice	282961	295765	307315	318490	330950	344937
Wheat	756428	774174	793149	812934	832746	852485
Cotton	413247	425431	437899	450674	463780	477214
Sugar Cane	377332	388350	400125	412412	424667	436772
Tobacco	162385	166536	171541	176998	182080	186639
Other Crops	715420	733617	752749	772567	792593	812765
Pulses/ Grams	295896	304570	313638	323012	332500	342067
Potato	295067	303602	312659	322079	331524	340933
Fruits	401161	411637	423008	434938	446752	458346
Vegetable	330060	339112	348829	358981	369095	379097
Oil Seed	326928	335049	345117	356188	366362	375339
Others	307099	313531	322769	333367	342467	349639
Livestock	2527522	2581016	2639157	2700141	2760713	2820512
Forestry	393867	402920	414257	426763	438211	448248
Fisheries	327801	336361	346083	356459	366459	375919

Note: unit of measurement is PKR

Table 7-3 Production under CI Scenario

Sectors	2012	2017	2022	2027	2032	2037
Rice	268812	280976	291948	302564	314402	327689
Wheat	718606	735464	753491	772287	791107	809860
Cotton	392583	404159	416003	428139	440590	453352
Sugar Cane	358464	368932	380117	391791	403433	414932
Tobacco	154264	158209	162963	168147	172975	177306
Other Crops	679648	696935	715111	733937	752963	772126
Pulses/Gram	281101	289341	297955	306861	315874	324962
Potato	280312	288421	297025	305974	314947	323886
Fruits	381102	391054	401857	413190	424414	435427
Vegetable	313556	322155	331387	341031	350640	360142
Oil Seed	310581	318296	327861	338377	348043	356571
Others	291743	297853	306629	316698	325343	332156
Livestock	2401145	2451965	2507199	2565133	2622677	2679485
Forestry	374172	382773	393543	405424	416299	425834
Fisheries	311410	319542	328778	338635	348135	357122

Note: unit of measurement is PKR

Table 7-4 Production under TC Scenario

Sectors	2012	2017	2022	2027	2032	2037
Rice	272495	284825	295948	306709	318709	332179
Wheat	728451	745540	763814	782867	801946	820955
Cotton	397962	409696	421702	434005	446626	459563
Sugar Cane	363375	373986	385325	397158	408960	420617
Tobacco	156378	160376	165195	170451	175345	179735
Other Crops	688959	706483	724908	743993	763278	782704
Pulses/Gram	284952	293305	302037	311065	320201	329415
Potato	284153	292372	301094	310166	319262	328323
Fruits	386323	396412	407363	418851	430228	441393
Vegetable	317852	326569	335927	345703	355444	365076
Oil Seed	314836	322657	332352	343013	352811	361456
Others	295740	301934	310830	321037	329800	336707
Livestock	2434042	2485557	2541548	2600276	2658608	2716195
Forestry	379299	388017	398935	410979	422003	431669
Fisheries	315677	323920	333282	343274	352905	362015

Note: unit of measurement is PKR

Generally, economic output is the highest for the BL since growth trends are isolated from climate change. However, under the CI scenario, the economic output value of all the crops decreased. For example, rice and wheat show a decrease of PKR-14 and PKR-38 billion respectively. The decrease in the production value of both major staple diets would increase price and reduce consumer welfare by reduction consumption. A similar trend can be found in the case of cash crops like cotton, sugarcane and tobacco. The highest loss of livestock has twofold reasons: first, it is one of the largest sectors of economy, second, it is based on the consumption of other sub-sectors of agriculture.

Table 7-4 reports results under the TC scenario, which shows the positive response of technical change action across all sub-sectors of agriculture. Although the sectoral output under TC is lower than BL but it is comparatively higher than CI output. This highlights the potential of technical change to counterbalance climate damages. It is also important to note that despite the optimal technical change the outputs are less than the BL scenario. This explains the limitation of technical change to overcome entire losses in the production, due to the continuous growth of CO_2 emission and temperature change.

We typically find that climate change is associated with significant distributional effects, and all impacts of climate change are negative. We present here the simulation results, by focusing on residual damages; which is the differences between the BL and another scenario. Residual damages show the reduction in the production of each sector of the economy. The conducting of this exercise has dual objectives: the first is to assess the economic consequences of climate change on agricultural production, and second is to verify the economic feedbacks of technical change actions on sectoral output. Further residual damages are computed under CI and TC scenarios, as indicated in Table 7-5 and 7-6 respectively.

Table 7-5 Residual Damages (CI Scenario)

Sectors	2012	2017	2022	2027	2032	2037
Rice	14149	14789	15366	15925	16548	17247
Wheat	37822	38709	39658	40647	41638	42625
Cotton	20663	21272	21895	22534	23189	23861
Sugar Cane	18867	19418	20007	20621	21234	21839
Tobacco	8120	8327	8578	8850	9104	9332
Other Crops	35771	36681	37638	38629	39630	40639
Pulses/Grams	14795	15229	15682	16151	16625	17104
Potato	14754	15181	15633	16104	16577	17047
Fruits	20059	20582	21151	21747	22338	22918
Vegetable	16503	16956	17442	17950	18455	18955
Oil Seed	16347	16753	17256	17810	18319	18767
Others	15355	15677	16139	16669	17124	17482
Livestock	126377	129051	131958	135008	138036	141026
Forestry	19694	20146	20713	21339	21911	22413
Fisheries	16391	16819	17305	17823	18323	18796

Note: unit of measurement is PKR

Table 7-5 shows a general reduction in production, livestock exhibits highest production losses of PKR-126 billion, while tobacco has only PKR 8.1 billion. Similarly, Table 7-6 displays a differentiated picture of damages that is expected due to the nature of technical change actions. Residual damages under TC shows consistent lower damages in all time segments. Indirectly it can be interpreted as the productions of each sector for TC is higher than that of the CI scenario.

The difference between the residual damage under BL and CI scenarios provides the impact of climate change, where the variation of residual damage under TC and CI scenario provide net benefits of technical change. Table 7-7 provides the net benefits of technical change for each sector. Results portray that the livestock sector obtained the largest net benefits worth PKR 32 billion followed by wheat and other crops with PKR 9.8 and 9.3 billion. It is also important to note that technical change redresses the climate damages from all the sectors. On top of that, all the sector gain net benefits due to spillover effects of technical change. Moreover, the net gains of technical change are 37 per cent higher than damage incurred by each sector.

Table 7-6 Residual damages (TC Scenario)

Sectors	2012	2017	2022	2027	2032	2037
Rice	10466	10939	11366	11780	12241	12758
Wheat	27977	28633	29335	30067	30799	31529
Cotton	15284	15735	16196	16669	17153	17650
Sugar Cane	13956	14364	14799	15253	15707	16154
Tobacco	6006	6160	6345	6547	6735	6903
Other Crops	26460	27133	27841	28574	29314	30060
Pulses/Gram	10944	11265	11600	11947	12298	12652
Potato	10913	11229	11564	11912	12262	12610
Fruits	14837	15225	15645	16087	16523	16952
Vegetable	12208	12542	12902	13277	13651	14021
Oil Seed	12092	12392	12765	13174	13550	13882
Others	11358	11596	11938	12330	12667	12932
Livestock	93480	95459	97609	99864	102105	104316
Forestry	14568	14902	15322	15784	16208	16579
Fisheries	12124	12441	12800	13184	13554	13904

Note: unit of measurement is PKR

Table 7-7 Benefits of Technical Change

Sectors	2012	2017	2022	2027	2032	2037
Rice	3683	3849	4000	4145	4307	4489
Wheat	9845	10076	10323	10581	10838	11095
Cotton	5379	5537	5699	5866	6036	6211
Sugar Cane	4911	5054	5208	5368	5527	5685
Tobacco	2113	2168	2233	2304	2370	2429
Other Crops	9311	9548	9797	10055	10316	10578
Pulses & Grams	3851	3964	4082	4204	4328	4452
Potato	3840	3951	4069	4192	4315	4437
Fruits	5221	5358	5506	5661	5815	5965
Vegetable	4296	4414	4540	4672	4804	4934
Oil Seed	4255	4361	4492	4636	4768	4885
Others	3997	4081	4201	4339	4457	4551
Livestock	32896	33593	34349	35143	35931	36710
Forestry	5126	5244	5392	5554	5703	5834
Fisheries	4266	4378	4504	4639	4770	4893

Note: unit of measurement is PKR

We proceed further to identify the macroeconomic impact of CI and TC. In doing so the difference between the real GDP of two scenarios is compared. It is also important to note that, detailed data and mechanisms behind the two aforementioned impacts is not explained explicitly. However, the interaction between the exogenous dynamics of changes in model parameters (simulating the effects of climate change) and the endogenous dynamics of capital accumulation will serve the purpose of our interest.

The model results of the estimated RGDP values (million Rupees) under three scenarios have been presented in Table 7-8. The BL scenario shows the highest real GDP as it is kept isolated from the adverse impact of climate change. It provides a reference growth trajectory for gauging the effects of climate change-induced damages. The results for the CI scenario are obtained by simulating a progressive change in temperature and CO_2 emissions. The general increase in temperature and CO_2 emission hits more severely to the agro based economy of Pakistan, which causes a reduction in real GDP of Pakistan.

It can be seen from Table 7-8 that climate change causes a reduction of 3.03 per cent in the cumulative real GDP i.e. The estimated value of real GDP decreased from PKR 9.9 trillion to 9.6 trillion in the base year. Hence, it shows that production is reduced by climate change and vis-a-vis consumption also decreased.

Table 7-8 Comparison of RGDP under Three Scenarios

Scenarios	2012	2017	2022	2027	2032	2037
BL	9936712	10245810	10559832	10880549	11211079	11551907
CI	9635638	9935371	10239878	10550878	10871393	11201894
TC	9845459	10150528	10460486	10777065	11103310	11439701

Note: unit of measurement is PKR

Similarly, it can be inferred that technical change is effective as the real GDP under technical change scenario increases by 2.13 per cent from the CI scenario and reached to Rs.9.8 trillion. It is also important to note that real GDP under TC scenario is still less than BL scenario by 0.92 per cent, but technical change is considerably effective in redressing the climate change effects on national output. Moreover, the aggregate impacts of TC scenario are projected to be beneficial in every time segment even though it accounts the additional cost of technical change.

In a similar way, Table 7-9 illustrates the value of economic losses in real GDP in all time segments. The losses are computed by taking the difference between CI and TC scenario real GDP with BL values.

Table 7-9 Real GDP Loss due to Climate Change (in Million)

Scenarios	2012	2017	2022	2027	2032	2037
BL-CI	301074	310439	319954	329671	339686	350013
BL-TC	91253	95282	99346	103484	107768	112206

Note: unit of measurement is PKR

From the above comparative analysis, it can be inferred that in the absence of technical change the economy will bear losses equal to PKR-301 billion. Where in the case of optimal scenario (TC) is enacted the monetary loss reduced to 91 billion. This shows the increase of output by PKR-209 billion in a base year where the rate of increase improved with the passage of time. Hence, it can be inferred that the option of optimal technical change is effected and can reduce the economic losses significantly.

7.3 Technical Change Government Expenditure and Private Consumption

The government expenditure is a must to implement a public policy. Thus, to enforce technical change actions, the government has to bear the costs of technical change. We examined the effect of technical change on government expenditures. This effect was estimated in all scenario. Table 7-10 show the estimated values of government expenditures before and after taking technical change actions. The results show a generally linear increase in government expenditure over time. However, in the case of TC scenario, government expenditure is 5.28 per cent higher than that of BL. The higher value indicates the additional investment expenditure that is needed to fulfill technical change actions. Similarly, government expenditure is 19.45 per cent less than that of the BL scenario. The lower value depicts that climate change reduced government consumption by reduced output, hence overall expenditure decreased significantly.

Table 7-10 Government Expenditure

Scenarios	2012	2017	2022	2027	2032	2037
CI	3192116	3158226	2636174	2665110	2934099	3017131
BL	3753603	3733798	3225044	3268816	3553701	3652465
TC	3963225	3946168	3439032	3486397	3775027	3877620

Note: unit of measurement is PKR

Similarly, to ascertain the effect of technical change on private consumption, the results of private consumption expenditure are compared under all the scenarios. Table 7-11 illustrates private consumption under the CI scenario decreased by 2.4 per cent as compared with BL scenario. This depicts that household consumption faces a reduction of PKR 561 billion on current consumption.

Similarly, TC scenario witnesses a 1.4 per cent increase in private consumption expenditure of households. The increase in private consumption shows that general household income is augmented due to the higher productivity of production system. In total, household income and consumption increased by PKR-209 billions.

Table 7-11 Private Consumption Expenditure

Scenarios	2012	2017	2022	2027	2032	2037
CI	14340863	14704486	15119666	15493085	15854285	16244998
BL	14902349	15280058	15708536	16096790	16473887	16880332
TC	14692698	15062638	15482803	15863572	16232543	16631069

Note: unit of measurement is PKR

The prime purpose of analyzing private consumption is to identify the welfare effects of technical change. From the results it is clear that technical change is economically effective; it has a significant positive impact on GDP and private consumption. Although it increased general government expenditure, its net effects are still significantly positive.

7.4 Discussion

The results compare the impacts of technical and climate change on the overall economy in general and agricultural sector in particular. The outcome under the CI scenario displays that climate change tempts severe damages to the agricultural sector and can lead to serious consequence for food production in near future, as the agricultural sector accounts for half of the cumulative losses as a percentage of the real GDP of the country. However, the situation looks bluer as the losses increased by 14.25 per cent in comparison with a base year in 2037. Comparatively, agricultural sector production in the CI scenario decreased by 5.2 per cent in a base year as compared to BL scenario. The reduction in crop production is much more diverse on downstream sectors. For example, livestock sectors show maximum losses followed by wheat and other crops, where tobacco crops shows the minimum losses.

These findings provide empirical support for a hypothesis, that contemporary and future economic damages from climate change will be severe for Pakistan agriculture. Given the threat posed by climate change for agricultural production, it is no surprise that the scientific literature is replete with modelling studies attempting to assess the impacts of climate change on future agricultural production. A wealth of global, regional, national and site-specific assessments of climate change impacts have been performed to date (Lobell et al., 2013; McCarl et al., 2008; Schlenker & Lobell, 2010).

However, assessment studies have focused mainly on agro-climatic components (Reilly et al., 2003) adaptation (Mendelsohn, 2000) and mitigation (Guariguata et al., 2008) to counterbalance agricultural damages. In contrast, this study models optimal technical change[47] strategy as a response to limit climate damages in the agricultural sector as done by Popp (2006) for the energy sector. Although, agroecosystems are inherently complex; it is difficult to achieve win-win outcomes from any climate response actions (Viner, 2006). Despite the cost tradeoffs of technical change, it is considered efficient as it redresses climate damages from agricultural production of Pakistan. The

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[47] Technical change is considered exogenous and Hicks's neutral.

results are in line with some of the previously conducted studies like (Ewert & Wagenhofer, 2005; Lal, 2004a).

Technical change has profound impacts on the agricultural sector of Pakistan because it is expressed in terms of TFP. Any increase in TFP means that more outputs can be obtained from a given level of inputs. Results suggests\ that agricultural TFP rises faster because aggregate increases in TFP have been implemented by adjusting exogenous Hicks's parameter. Similarly, downstream agricultural sector shows a positive response to technical change. It is not surprising that the livestock sector would experience the largest output increase, given its more intensive use of crop products as inputs. Since most of the crops (act as intermediate inputs for livestock) show positive gains in production and consequently livestock product shows the highest increase in output. However, this increase in production is still smaller as compared to the global average (FAO, 2013). Furthermore, the positive changes in the production of agricultural sub-sectors reflect the changes in the comparative advantage of agriculture. As crop production will face less damage by future changes in climate, as indicated by residual damages, producer prices will fall relative to the international prices of crops, leading to more exports and fewer imports in the crop sectors (Godfray et al., 2010; Holst et al., 2013).

Thus, the co-benefits of technical change may become important with the expected global food demand hike in coming decades (Sanchez & Swaminathan, 2005). Furthermore, technical change not only enhances agricultural production but also increases the resilience of the whole agricultural system to curb climate change (Poloczanska et al., 2013; Rosegrant & Cline, 2003; Vermeulen et al., 2012). The efficiency of technical change in agriculture depends on its capability to encapsulate all aspects of agricultural systems (IPCC, 2011) especially productions of most vulnerable downstream sectors (Waha et al., 2013).

Altogether, agriculture being one of the largest sectors of the Pakistan economy, needs critical attention due to impending threats of climate change. However, the current non-responsive attitude at the government level represents a possible connection with the "dumb farmer hypothesis". Nevertheless, this hypothesis has been used in numerous impact studies; specifically, to estimate damage from extreme weather events, morbidity, hunger, health etc. (De Salvo et al., 2013; Fankhauser et al., 2010). The capacity to reduce climate-change impacts on agriculture has a strong nexus with future technical change. In Europe technical change counteracts the negative impact of climate change in the agricultural sector (Smith et al., 2005). Similarly, based on technical change scenarios developed by (Rounsevell et al., 2005) found that socio-economic characteristics of technical change strongly affects emissions, therefore, the pace and extent of climate impact also harmonized as suggested by (Berry et al., 2006).

To calculate an aggregate damage value of the climate change, economic costs of technical change are added with residual cost (Pearce et al., 1996) , hence, damages are a constant fraction of GDP and grow linearly with GDP. The linear trend of climate damages can be influenced by other factors shifting a number of damages up or down. For example, population growth affects the number of people concerned and then income growth affects people's evaluation of impact; this result in a change of tastes affecting valuation (De Bruin, K. et al., 2009). To encapsulate the effects of this factor our model included Pakistan income and population data to get different damage values for each time segment.

Real GDP shows a noticeable decline of 3.02 per cent under the CI scenario as compared with BL in contrast with the 1.4 per cent of global value as shown by Zhai et al. (2009). According to the findings Xiong et al. (2010), India is suffering the largest GDP loss of 6.2 per cent, followed by sub-Saharan Africa, South and Central Asian countries. Although findings for Pakistan are above the global average, but are lower than India. Additionally, China is expected to see a drop in real GDP of 1.3 per cent, which is slightly lower than world's average. According to another study by Cline (2007) New Zealand is the only country that would experience an increase in real GDP by 2.2 per cent as a result of climate change.

While aggregate welfare effects of climate change generally follows a reduction in real GDP, price adjustment plays a role in the distribution of welfare losses. After the incorporation of agricultural damage, the prices of crop products were projected to climb by 16 to 22 per cent reflecting the inelastic demand structure of agricultural products. This will generate changes in terms of trade. The resultant changes in terms of trade would benefit net agricultural exports but damage net agricultural imports. By deteriorating terms of trade, effects of agricultural damage will be amplified, and welfare losses will generally be larger than the GDP decline.

In contrast, real GDP under the TC scenario shows an increase of 2.13 per cent from the CI scenario level. This is mainly because of technical change caused by productivity improvement in agricultural and other related processing industries. Moreover, technical change yields reallocation of resources across sectors that offset the direct impact of climate change on productivity slowdown. In this way, it contributes to the expansion of all sectors' production and yields higher GDP. Further, positive impact on real GDP reduces the aggregate price level and improves aggregate real household consumption. Increase in real household consumption can be considered as an indicator of the welfare improvement by the rise in productivity.

In the context of socio-economic impacts, climate and technical change illustrates that climate change directly affects consumption of livelihoods through their impacts on production (agricultural and non-agricultural) and income. The direct or indirect interplay between climate change on one hand and private consumption on the other eventually determines the final welfare impact of climate change. Private consumption witnesses a decreasing trend in the CI scenario with respect to BL. The reduction of private consumption is courtesy of the direct impact of climate change on production and income level of households. As can be seen from climate impact studies like Rabassa et al. (2014) and Skoufias and Vinha (2013) that changes in weather conditions will directly reduce the production of most vulnerable sectors like agriculture and fisheries. Similarly, production shortfalls, food price hike and decreases in net incomes ultimately reduce the level of consumption (McMahon et al., 2011).

Moreover, the relative effectiveness of technical change action is not equivocal, as the private consumption increases in TC scenario. The effects of technical change took place in two steps. Initially, technical change reduces the harmful impacts of climate change on the vulnerable sectors of economy e.g. agriculture. Secondly, reduction of climate endorsed changes will facilitate production, therefore, the production levels of all the sectors of the economy increase over time. The increase in production reduces the prices and increases the income level of households. These two effects jointly increase the consumption level as shown in the TC scenario. Hence, we can conclude that technical change by and large affects the productivity trend in case of Pakistan. More importantly, it produces a noticeable influence on the real income and consumer wealth, as inflation is reduced, which puts positive influence on private consumption.

Similarly, government expenditure can be influenced by climate and technical change in many ways. For example, climate change has significant economic and fiscal repercussions (Ouattara & Strobl, 2013). The literature often argues that in the times of economic upturns income levels and government expenditures tend to increase and vice versa (Shelton, 2007). Climate change damages reduce the income level, which ultimately causes a reduction in the government's expenditure (Durevall & Henrekson, 2011). Similar, results have been found in all scenario simulations. Government expenditure under CI scenario was less than in the BL scenario. In contrast, TC scenario simulations show that expenditure increases, above the BL level.

The increase in expenditure is endorsed by two factors, firstly it overhauls the negative impact of climate change and increases income and secondly, the cost of technical change action has been added by investment expenditure. We can infer from the estimated results that technical change needs additional investment and hence it will increase the overall government expenditure. Although the literature on fiscal costs and benefits of climate change is scarce, yet our results are supported by Osberghaus and Reif (2010). They provide "guesstimates" of public investments for European countries to mitigate climate change.

Likewise, the World Bank also endorses that developing countries need additional investment in various economic sectors to overcome climate damages. Bulkeley and Kern (2006) shows direct and indirect effects of climate change mitigation on government finances in Germany. They estimate that any mitigation action would increase government expenditure, which is equal to 0.6–2.5 per cent of GDP as compared to a reference scenario. Similarly, Heipertz and Nickel (2008) conclude that any climate response policy impact on public finances will be between 0.3–1.1 per cent of GDP.

It is clear from the above discussion that macroeconomic impacts of increasing agricultural productivity are not marginal. The results showed that increasing agricultural productivity would generate positive economic benefits to the country as targeted in the development framework. The increase in agricultural productivity stimulates the growth of manufacturing and services sectors besides agriculture.

7.5 Summary

This chapter starts with comparing the agricultural production for checking the effectiveness of technical change. Further, the residual damages are calculated, and monetary benefits of technical change for agricultural production are identified. From the residual damage analysis, agricultural production under the TC scenario proved more efficient. To identify the macroeconomic impact of technical change real GDP is compared along with government expenditure and private consumption. Results reveal that technical change has the potential to redress climate change impact on the economy and agriculture sector. Similarly, it is found that technical change has overwhelmingly large welfare impacts.

CHAPTER 8: CONCLUSION

8.1 Summary of Findings

This study focused on the effects of Hicks's neutral technical change (TFP) on the performance of agricultural production in Pakistan under changing climatic conditions. The study has three objectives. First, to identify the effects of climate change on the agriculture sector by decomposing them on crop specific levels. Second, to determine the optimum level of Hicks's neutral technical change, which can nullify climate damages on agricultural production. Third, to estimate cost and benefits of the investments involved in implementing technical change in agriculture and the overall economy.

The empirical strategies involved several steps. First, the Social Accounting Matrix (SAM) for Pakistan was constructed using the latest available input-output table and national accounts data. For all economic activities, impacts are converted into a common unit on the total amount as monetary value and then calibrated into common units based on the generated economic data from the SAM. The study adopts the Empirical Dynamic Computable General Equilibrium Model, in such a way that special emphasis was deemed on modelling the agricultural sector of the Pakistan economy. Second, three scenarios were constructed in order to run simulations based on the climate change imposed issues in Pakistan's agricultural sector. The model links exogenous climatic factors such as climatic damage, carbon cycle, temperature and rainfall fluctuation, carbon emissions, vulnerability and carbon concentration, which affect agricultural production. Third, the baseline parameters and coefficients required for the implementation were obtained based on the constructed database.

To begin with the simulation analysis, trends in carbon emissions and temperature changes are traced through the historical data. The projected results show that CO_2 emissions and temperature increase over time i.e. 2012 to 2037. However, the temperature increase is found to be higher than the global average (Griffiths et al., 2005) in Pakistan, suggesting that the economy is relatively more vulnerable to climate atrocities vis-a-vis other countries. Hence, future climate conditions for the Pakistan would be different from the rest of the world.

The model showed different trends for agricultural production under three scenarios. By applying the Climate Impact (CI) Scenario simulations, the monetary impacts of climate change on agriculture were determined. Although climate change has its profound impact on the entire economy of Pakistan, but on a relative prioritization basis, the agriculture sector is ranked on top being most susceptible to weather extremes. The most extreme climate model scenario (CI) foresees, for an agriculture sector that high temperature and escalated CO_2 emissions, deterioration in the production of all kinds of crops and livestock. The results further affirm that production damages significantly differ across sectors, where its scale is found to be highest for livestock and lowest for tobacco. Additionally, about half of the climate damage to the economy of Pakistan is borne by the agricultural sector alone.

Further, the study tests technology potentials to rectify climate damages on the economy in general, and the agricultural sector in particular. In doing so, we model the Hicks's neutral technical change exogenously under technical change (TC) scenario simulations. After conducting various simulations, the optimal level of neutral technical change was obtained. From the model calibration, the optimal level of Hicks's neutral technical change for the agricultural sector of Pakistan is determined at 1.3 per cent. In other words, 1.3 per cent increase in production efficiency is needed to overcome climate damages from Pakistan's agriculture sector. The results show significant positive effects of the technical change to mitigate climate damages. The overall economic damages of climate change are reduced significantly when there is technical change. Further, crop yield predictions under TC scenario shows that all crops have steady yields, which would increase production. Hence technical change moderates the damages of climate change, in the agricultural sector.

However, investment in knowledge improving activities that have strong public good qualities is fundamental to obtaining the optimal level of technical change. Hence, investments involve expenditures, which provide future productive payoffs. The projections reveal that investment costs of technical change are initially high as a percentage of GDP but later reduces due to spillover effects of technical change. In addition, there is enormous heterogeneity in investment requirements across the agricultural sub-sectors. For example, the investment cost for livestock is higher due to higher damages incurred in this sector, while the cost for tobacco is lowest because it is a cash crop. The technical change (TC) simulations show significant increases in the production for all sub-sectors of agriculture, which satisfy the Hicks-Kaldor Criterion (Hicks, 1939). The results also conclude that production of each sector is higher in the TC scenario, even with the subtraction of investment cost.

Finally, the predicted/expected responses of the potential costs to the potential benefits in three scenarios are compared to identify net gain. The comparative analysis shows that the residual damages brought about by the CI are higher than of the TC scenario. It is evident that technical change decreases the losses by increasing efficiency in the production process, hence real GDP in TC scenario is higher than that for CI. Notwithstanding the positive effects of technical change for mitigating climate damages, there are significant economic and fiscal repercussions based on the expenditure patterns of the public and private sectors. Following investments in technical change, government expenditure is expected to escalate from the baseline (BL) scenario. In the case of the CI scenario, government expenditure is found to be lower than the BL scenario. Conversely, private consumption expenditure would increase under the TC scenario because technical change generates production efficiency, which in turn increases production and income of households.

The core findings of the effects of technical change on agricultural production are:

I. Climate change significantly reduces agricultural production, with severe losses encountered by key sectors like livestock.
II. The benefits of technical change are higher than the overall costs from climate damages to the economy and for all sub-sectors of agriculture. Thus, the economy would benefit with an optimal level of investment in technical change.
III. In agriculture, the benefits of technical change are high in terms of monetary impacts from production.

8.2 Implications of Study

This study has generated a number of implications that would be of interest to policy-makers. Several of these implications are discussed below. It should be stressed that the ideas presented are by no means exhaustive. They are, however, intended to stimulate thinking on how the insights from this study might impact, in a very broad way, the agricultural sector of Pakistan economy. Recognizing that there are serious yield gaps and climate change is exacerbating yield condition by incurring damages to the production of major crops in Pakistan. Our analysis portrays a significant influence of a technical change in mediating climate damages from agriculture sector of Pakistan. On the basis of above, empirical findings of major policy implication can be derived that the government needs to allocate more resources for investments in technical change specifically in the agricultural sector, namely sub-sectors that are more susceptible to climate change.

Currently, the share of total government expenditure on agriculture provides important information about the biased treatment of agriculture. The country was investing between 0.2 per cent on agricultural research, whereas India was investing 0.4 per cent, Bangladesh 0.35 per cent, China 0.6 per cent and Japan 2.5 per cent. On the other hand, the developed world was investing 2 to 3 per cent on agricultural research. Additionally, the share of public investment in agriculture has declined substantially in the last few decades. In relation to the total development expenditure, the share of agriculture has compressively declined to 18 per cent as stated in the last 10-year Plan of Pakistan (GoP, 2012).

The small amount of spending suggests that the agricultural sector is underfunded. Therefore, going forward as natural resources come under stress; agriculture production could suffer a great deal with climate change, hence countries need to revisit their policy priorities. Current agricultural production may not be able to sustained growth rates to feed the burgeoning population. Most food supply and demand projections for Pakistan forecast large agricultural commodity imports in the future if investment in the agricultural sector remains at this low level (Zhu et al., 2013).

Additionally, most of the government investment is channelized to import technology from developed countries. This leads to an adaptive research attitude particularly for grain and fiber crops, where focus should be on productivity enhancement activities. As various research output highlighted that TFP of livestock and major food & fiber crops will further decline due to adverse climate conditions. On one hand, average TFP under climate change conditions reached to 0.6 per cent, while on the other hand potential of increasing productivity through investing in agricultural research and innovation has not been tapped.

On top of that, the largest fiscal expense of government in the agricultural sector is the provision of subsidies to key agricultural inputs, which cover fertilizer, seed, tractors, and tube wells, etc. Instead of investing in research and innovation, Pakistan’s agricultural sector is focused on increased use of inputs, which led to stagnation in productivity. Moreover, due to leakages and inefficiency in state organizations, the benefits of government interventions has not reached proper agricultural consumers. Such interventions have ensured an adequate supply of food staples, and the resulting economic costs has become a growing concern.

Our analysis reveals that investment in technical change is particularly important to maintain a steady production growth of the agricultural sector. Economically, technical change will facilitate the efficiency of the production process, hence, costs of production will decrease and prices will stabilize under changing climate conditions. Therefore, this study suggests that investment should be channelized in technical change actions.

In this regard government should make farmer’s education a top policy priority. The role of education in improving efficiency and technology adoption has been well established (Feder et al., 1985; Lockheed et al., 1980; Phillips, 1994). However, education is a long-term process which will take many years to yield benefits. Therefore, this study suggests that government should prioritize modern agricultural practice training in the short run as a firefighting policy. Where, in the long run, the government needs to promote an education that had quality and has its relevance to the farming profession. Highly trained and well-educated farmers will actively engage in improving the technical and allocative efficiency of agricultural activities.

Moreover, an educated workforce is easier to train and acquire new skills and technologies required for productivity growth. As future agriculture will increasingly be science led and will require modern economic management, high returns on investment in education are expected. Education has to be recognized as a pre-requisite for technical change, and investment in education is synergistic, leading to greater utilization and deeper impact of investment in other areas of social infrastructure such as healthcare, nutritional security, sanitation, and the environment.

Pakistan is passing through a severe energy crisis, which causes inflation in agricultural inputs. Current climate dynamics coupled with energy shortfall make small farmers most vulnerable to production catastrophes. Since small farmers constitute the largest segment of agricultural society the government should take concrete measures to address their survival. In this regard the government can exclusively tailor need-based productive programs for struggling farmers. Especially, skill development programs will make them better decision-makers and highly productive. Human resource development for small farm holders should be given high priority in policy agenda along with education. Moreover, necessary safety nets need to be built to protect small farmers from the globalization, liberalization reforms, and the WTO regime in the structural adjustment processes. Since the surplus of small farmers is small, the policy must be designed to insulate domestic markets from the shocks of international markets. Thus, awareness and skill development of small farmers is essential for achieving production goals in the realm of climate change.

Technical change is a tenet of gambling, the decision on whether to conduct any capital investment is a risk. The justification of investment depends on evaluation, not only of potential losses versus potential gains but also of whether those potential losses are manageable in relation to assets already owned. The farmers are not well equipped to take such risk, hence the role of government in this regard becomes important. The government should create a necessary policy environment to neutralize the risk factor. The possible ways in this regard are diversification, generation of new livelihoods, off-farm income, institutional support, access to information, technology, credit facilities, crop insurance, etc.

The wide yield gaps of major crops and livestock commodities is another important area to focus on, in particular livestock which can, quite rightly, be called the country's hidden secret. However, with 3rd largest livestock population, the average yield of milk per animal is one of the lowest in the world. In this regard, the role of the government is to create a conducive environment for exploiting investment opportunities in breed improvement, animal husbandry, veterinary medicines. Moreover, there is a need to establish an appropriate network of extension services which can stimulate both top-down and bottom-up flows of information among farmers, extension workers, and research scientists to promote the generation, adoption, and evaluation of location-specific farm technologies. In the case of crops, ample scope exists in increasing genetic yield potential of a large number of vegetables, fruits as well as other food crops products. Thus, the government should aggressively promote a programme-based approach to facilitate integrated pest and nutrient management. This will generate greater congruency between productivity and sustainability to bridge yield gaps in most field crops.

The obsolete nature of agricultural infrastructure is another major problem of productivity laps. To enhance productivity creation of infrastructure that can facilitate technical change is of the utmost importance. In connection with point mentioned, the government can focus on public investment of infrastructure development. In light of resource depletion courtesy of climate change, degradation of land and water resources, investments that are good for rural infrastructure such as roads, education, and irrigation amount to a ‘win-win’ strategy for reducing climate damages from the economy and agricultural sector of Pakistan. The better architecture of infrastructure will remove barriers of technical change and stimulate technology growth. There has been a considerable expansion in international and national support for agricultural research during the past three and half decades. However, annual growth in total research expenditure in Pakistan has declined in real terms (GoP, 2015).

Moreover, for enhancing agricultural productivity, investment in R&D depends significantly on the institutional architecture of the system in which scientific knowledge and technology is produced. The institutional arrangements of Pakistan are highly bureaucratic, which impose multiple hurdles on research and innovation. From an institutional perspective, this requires a reconciliation of the divergent interests and objectives of public institutions, private firms, and agrarian agents in the national system. In terms of policy and action, this requires significant public sector reform, partnership between the public and private sectors, and strategic leadership from public agencies.

Technologically, this means pursuing innovations that are productivity enhancing, labour-using, land-neutral, capital non-intensive, and risk-reducing. This will balance the use of an advance scientific knowledge and technology with traditional or conventional knowledge and technology. Moreover, government needs to encourage not only those R&D expenditure that have immediate, global, and regional applicability, but also prioritizing those innovations that require long-term, location-specific investments. Besides that, major policy reforms in marketing and macroeconomic policies are needed to encourage long-term investment and technological changes in agricultural sector.

The above discussion identifies dimensions of Hicks's neutral technical change that are important for addressing climate damages. We suggested to the government to consider these factors when developing climate change policy. However, when devising the policy, heterogeneity of climate damages across downstream agricultural sector must be taken into account properly. Our results depict that climate damage across sectors differ, while climate impacts are homogenous. This situation requires a smart mix of policies. The government can adopt a one-fit-all policy for education and health. However, policies to promote new skills and training need to consider the type of sector, its size, and its climate damages.

8.3 Contributions of Study

8.3.1 In Terms of Theory

The theoretical contribution of the study can be divided into two parts. First is the integration of country-specific climate in the modelling framework. Second is the assignment of specific agricultural Hicks's neutral technical change in the model structure to find optimal climate damage reduction exploration. Fundamentally, from the theoretical perspective, the current study has used three basic theories and their effects as a basic framework to gain a better understanding of the impact of climate change on agricultural production. As discussed earlier, factors of natural capital theory extended the analytical horizon in explaining agricultural production from the production economics approach.

This study uses aforementioned theoretical coherence to explore the impact of climate variables on natural capital. Further, by examining climate damages to agricultural production it explores that health of natural capital is a valid contributory determinant in agricultural production. Moreover, the quality of natural capital is rooted in the variation of climate parameters. Further, while production theory has been widely used in exploring production activities in agriculture, this study extends its existing production theory's arguments further to investigate the impact of climate variables in more details. Hence, this research contributes to an understanding of the nature of generalizability of the theories by extending their views into an additional area; the impact side of climate change on a sector specific level.

The study has also contributed to methodology by developing and validating some of the new reliable and valid measures in such academic practices. In doing so this study offers an innovative analytical and methodological approach for accessing the effects of climate change on sectoral agricultural production. Most of the existing theoretical contribution does not sufficiently address the impacts of climate change on the agricultural sector considering its interaction with rest of economy. The introduction of climate parameters in general equilibrium modelling framework provides new insights into the mechanism by which climate change affects agricultural production as a whole. The uniqueness of this approach is assigning weight to climate parameters that affect agricultural production, while considering the relationships with other economic sectors. This alignment of the present climate parameters in the theoretical framework value adds in the existing literature by providing comprehensive outcomes of climate damages. The new arrangements of the theoretical framework are productive in a way that it can segregate the damages across all subsectors of agriculture according to their importance in the economy. Moreover, the dynamic nature of the theoretical framework helps to identify future evolution of the agricultural sector and how it is affected by variations of climate change projections for the future.

The fiscal and growth complexities of Pakistan make climate change mitigation and adaptation difficult to materialize. Additionally, the research with a specific focus on the nexus between agricultural production and climate change is limited for Pakistan. Therefore, to disentangle the damages of climate change from the economy in general and agricultural sector in particular, this study introduces a unique approach to integrating the ‘Integrated Assessment Model’ into the general equilibrium modelling framework. In doing so, this study provides technical change as a measure to redress climate damages from the agricultural sector in particular and the economy in general. The technical change is modeled exogenously; following neo-classical growth theory, and the exogenous setting helped to overcome the thorny aspects of modelling endogenous technical change in environmental and climate modeling. In most climate and economy framework technical change is modeled exogenously as an autonomous energy efficiency improvement (AEEI) parameter.

In our framework, we present Hicks's neutral technical change as an exogenous parameter. The exclusive linkage of Hicks's parameter with the agricultural sector represents its neutral productivity gain, which is the distinctive feature of this study. The study framework not only sticks with overall damages but it segregates the effects of Hicks at sectoral level which adds to existing state of knowledge. This framework is built with the specific focus on the agricultural sector; however; construction of methodology is replicable to develop climate damages specific to any sector in Pakistan or any other country.

8.3.2 In Terms of Empirics

The conceptual schema proposed in the theoretical model is validated with the use of a good data fit. Therefore, this study empirically contributes to the literature by validating the impact of climate variables in the comprehensive general equilibrium modelling framework together with the Integrated Assessment Model. The study made contributions in empirical literature a numbers of ways. In the numerical ground, the developed modelling framework under a new empirical research setting drawn from extant theories satisfies all conditions with a desired level of data fit. Fundamentally, from the empirical perspective, the current study has estimated the climate change effects on the agricultural sector in monetary values under changing the likely climate conditions. Intrinsically, most of the existing climate studies investigated climate damages on an aggregate level; this study has put it forward one step further by examining sectoral climate damages in detail with the expected scenarios. The quantitative inclusion of damages across sub-sectors would contribute to enhancing knowledge for designing sectoral level climate strategies for relevant policy issues.

Principally, the study has discovered the significance of Hicks's neutral technical change to equalize climate damages for the agricultural sector, and determined the optimal level of Hicks's neutral technical change, which may efficiently restore climate damages for the Pakistani incident. The innovative feature that is extended from the existing related studies in one-to-one basis of climate damages that would help policy makers with precise knowledge to redesign the national climatic action plan considering details scenarios on sectoral impacts of technical change measures. Particularly, this study would assist the government to analyze the level of investment demand on sectoral level to neutralize the likely climatic effects and support long-term national policy framework for Pakistan in response to Pakistan National Climate Change policy (2012).

To conclude from an exclusively analytical point of view, the study has contributed by introducing Hicks's neutral technical change as a remedial measure for climate damage in agriculture for the first time for Pakistan.

8.3.3 Future Research

We suggest future researchers include data on other climate parameter and carpet to have a better representation of the agricultural sector with more micro-level orientation. On the other hand, we urge researchers to narrow the scope of the study and focus on individual crops to give a specific picture. The results of those studies can be compared with this study to ascertain the difference.

8.4 Limitations of the Study

It is well documented that computable general equilibrium (CGE) modelling is a very powerful tool. It allows economists to forecast the effects of future policy changes that would be impossible with econometric estimation. However, the models have their limitations. First, CGE simulations are conditional predictions and based on thought experiments about what the world would be like if the policy change had been operative in the assumed circumstances. Second, in term of econometric modelling they have limited possibilities for rigorous testing against experience; hence, CGE models are basically theoretical. Third, the model is based on the systematic behavior of the parameters, and therefore are readily prone to sensitivity analysis. However, conducting sensitivity analysis on the base data is difficult because altering one element of the base data requires compensating changes elsewhere in order to keep the national accounts and social accounting matrix in balance.

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LIST OF PUBLICATIONS AND PAPERS PRESENTED

Ahmed, A., Al-Amin, A. Q., & Devadason, E. S. (2016). Implications of Climate Change Damage for Agriculture: Sectoral Evidence from Pakistan. *Environmental Science and Pollution Research*. DOI: 10.1007/s11356-016-7210-3 (**Q1**)

APPENDIX A: LIST OF MODEL VARIABLES

PM_C = Import price in DCU (domestic currency units) including transaction costs

EXR = Exchange rate (DCU per FCU)

PEC = Export price in DCU

QQ_C = Quantity of goods supplied to domestic market (composite supply)

PX_C = Aggregated producer price for commodity

PD_C = Domestic sale price

QD_C = Aggregate quantity of domestic output

QE_C = Quantity of export

PA_a = Price of Activity

PX_c = Producer Price for Commodity (Aggregate)

$PVAa$ = Price of value add

PQc = Price of composite good

QA_a = Level of activity

QAC_a = Level of activity with climate change

Y_a = Gross output

$RGDP_t$ = Real gross domestic product

PVA_a = Value added price

$QINT_{ca}$ = Quantity of commodity c as intermediate input to activity A

YF_f = Total factor income

CPI = Consumer price index (Numeraire)

MPS = Marginal propensity to save

$IADJ_t$ = Adjustment factor

EG_t = Government spending

QFS_f = Quantity supplied of factor (exogenous and fixed

CC_t = Net consumption

ND_t = Net damages due to climate change

GD_t = Gross damages

RD_t = Residual damages

$ADPC_t$ = Adaptation cost

$F(T)$ = Radiative forcing

$M_{AT}(T)$ = Atmospheric mass of carbon reservoir

$F_{EX}\ (T)$ = Exogenous radiative forces

$\Omega(T)$ = Climate damages

$\varphi 1$ = Damage intercept

$\varphi 2$ = Damage coefficient

$\varphi 3$ = Damage exponent

T_{AT} = Global mean surface Temperature

$MAT_{(T+1)}$ = Atmospheric concentration of Carbon

E_T = CO_2-equivalent emissions GtC

LAM = Climate model parameter

$C1$ = Climate-equation coefficient for upper level

$C2$ = Transfer coefficient upper to lower stratum

AL = Adaptation level

$\gamma 1$ & $\gamma 2$ = Fraction of output per adaptation level

APPENDIX B: LIST OF MODEL PARAMETERS

$pwmc$ = Import price in foreign currency units (FCU)

$pwmc$ = Import price in foreign currency units (FCU)

tmc = Import tariff rate

$pemc$ = Export price in FCU

te = Export tax rate

tqc = Sale tax rate (composite price share)

$icac$ = Non-exported commodities

$cwtsc$ = Commodity weights in consumer price index

σa = Shift parameter (Efficiency parameter)

γf = Hicks’s neutral technical change

$WFDIST_{fa}$ = Factor market distortion parameter

αfa = Production function share parameter

$icaca$ = Quantity of c as intermediate input per unit of activity A

θac = Yield of output c per unit of activity a

αc = Shift parameter: CET function

δc = Share parameter: CET function

ρc = Exponent of CET function

$shryhf$ = Share of household h in factor income f

tr_{ROWf} = Transfer of factor income to ROW

tff = Value added tax on factor of production

βch = Consumption spending share of household

$qinvbar$ = Base-year fixed investment

η = Temperature forcing parameter

$b11$ = Carbon cycle transition matrix

$b21$ = Carbon cycle transition matrix

α_c^q = Shift parameter of Armington function

δ_c^q = Share parameter of Armington function

ρ_c^q = Exponent of Armington function

APPENDIX C: SECTOR CLASSIFICATION

Section	Divisions	Description
A	01 - 03	Agriculture, forestry and fishing
B	05 - 09	Mining and quarrying
C	10 - 33	Manufacturing
D	35	Electricity, gas, steam and air conditioning supply
E	36 - 39	Water supply; sewerage, waste management and remediation activities
F	41 - 43	Construction
G	45 - 47	Wholesale and retail trade; repair of motor vehicles and motorcycles
H	49 - 53	Transportation and storage
I	55 - 56	Accommodation and food service activities
J	58 - 63	Information and communication
K	64 - 66	Financial and insurance activities
L	68	Real estate activities
M	69 - 75	Professional, scientific and technical activities
N	77 - 82	Administrative and support service activities
O	84	Public administration and defence; compulsory social security
P	85	Education
Q	86 - 88	Human health and social work activities
R	90 - 93	Arts, entertainment and recreation
S	94 - 96	Other service activities
T	97 - 98	Activities of households as employers; undifferentiated goods- and services-producing activities of households for own use
U	99	Activities of extraterritorial organizations and bodies

APPENDIX D: SECTORAL ELASTICITIES

Sector	Elasticity of Substitution (CES)	Elasticity of Transformation (CET)
Rice	0.9	2
Wheat	0.9	1
Cotton	0.9	1
Sugar Cane	2	2
Tobacco	0.9	1
Other Crops	0.9	2
Pulses & Grams	0.9	1
Potato	0.9	1.5
Fruits	0.9	1
Vegetable and Other Condiments	0.9	2
Oil Seed	0.9	2
Others	0.9	1.5
Livestock	0.9	2
Forestry	0.75	2.5
Fisheries	0.75	2.5
Industry	0.5	2
Services	1.5	2