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The Impact of Climate Change in Bangladesh on the Rice Market and Farm Households

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The Impact of Climate Change in Bangladesh on the Rice Market and Farm Households

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by

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Abstract

Bangladesh is trying to achieve self-sufficiency in domestic rice production but climate change effects on agricultural production makes it challenging to attain the goal. The country is highly vulnerable to the effects of climate change since it is the major cause to rise in sea level, more warm summer, and happening food and cyclone in the country.

This study develops an Aggregate Farm Household Model to analyze the impact of potential land loss and yield reduction from climate change on production, consumption, prices, welfare, and the ability of government to achieve self-sufficiency in rice production. The model is calibrated to the Bangladesh rice market in three alternate scenarios using Household Income and Expenditure Survey, 2010 data. The results show that climate change leads to decline in productivity and increase in price of rice in the domestic markets. The reduction in rice productivity decreases rice production while increases production of other non-rice crops. Simulation with a 25% reduction in arable land and 15% reduction in productivity also found that rice land and non-rice agricultural land are also decreasing day by day. However, the decline in rice production leads to greater imports making food security harder to achieve.

From simulation analysis, rice yield reduces by 12.67% whereas, the rice price increases by 22.38% and imports by 5.20% with decline in rice productivity by 15% and arable land by 25% in Bangladesh. Alternatively, non-rice crop production increases by 0.19% and the price of non-rice agricultural products decreases by 1.33% in the same scenario. Consequently, the rice and non-rice consumption reduces by 2.28% and 26.24% respectively in both alternate scenarios. The change in climate has more negative effects of consumption of non-rice compared to rice because of the subsistence consumption for rice.

In summary, the decline in rice productivity and reduction of arable land leads to a decrease in rice yields, agricultural land and consumption of rice, non-rice agricultural goods, manufacturing goods, and leisure which leads to a reduction in the welfare for the farm households in Bangladesh.

Acknowledgments

First and foremost, I thank Almighty for seeing me through this program successfully.

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Dedication

This thesis is dedicated to the Almighty, the one who has given me strength and grace to go through my two years of graduate education. It is also dedicated to my beloved parents, who together played major roles in nursing and educating me.

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List of Acronyms

BBS	Bangladesh Bureau of Statistics
BCCSAP	Bangladesh Climate Change Strategy and Action Plan
BRKB	Bangladesh Rice Knowledge Bank
CCTF	Climate Change Trust Fund
cm	Centimetre
CO_2	Carbon dioxide
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
gm	Gram
GoB	Government of Bangladesh
ha	Hectares
HIES	Household Income and Expenditure Survey
IAPP	Integrated Agricultural Productivity Project
IFAD	International Fund for Agricultural Development
IFPRI	International Food Policy Research Institute
INGOs	International Non-Governmental Organizations
IPCC	Intergovernmental Panel on Climate Change
kcal	Kilocalories
kg	Kilogram
km	Kilometer
MDGs	Millenium Development Goals
MoA	Ministry of Agriculture
MoFDM	Ministry of Food and Disaster Management
NGOs	Non-Governmental Organizations
^{o}c	Degree Celsius
ppm	Parts per million
ppt	Parts per thousand
ROW	Rest of the world
SDGs	Sustainable Development Goals
UN	United Nations
UNDP	United Nations Development Program
USDA	United States Department of Agriculture
WB	World Bank
WFP	World Food Programme
$	Dolllar (US)
%	Percent

Chapter 1: Introduction

1.1 Background

Agriculture is the main source of livelihood for rural households in Bangladesh. Rice is the most significant cereal food and is cultivated on about 78.16% of the total crop production area (BBS, 2014), which indicates rice dominates agricultural production. With a per capita consumption of 416 gm per day, rice alone is contributed to 62.0% per capita daily calorie intake at the national level from 69.8% of total calorie received from cereals (BBS, 2010; HIES, 2010). While Bangladesh has achieved significant growth in domestic rice production, Bangladesh is still a predominantly net food importing country (Wailes and Chavez, 2012) and about 350,000 metric tons of rice are estimated to imports during fiscal year 2015/2016 (USDA-Grain and Feed Annual, 2016). As a part of the Millennium Development Goals (MDGs) the government of Bangladesh has tried to achieve national food security but still 16.4% people are food insecure (GoB, 2015a). At the UN General Assembly on Sustainable Development Summit held in 2015 the member states have adopted a set of 17 Sustainable Development Goals (SDGs) and 169 targets. Now, Bangladesh has moved to MDGs to SDGs targeting eradicate poverty and hunger, achieve food security and improved nutrition, and promote sustainable agriculture by 2030 (GoB, 2015b).

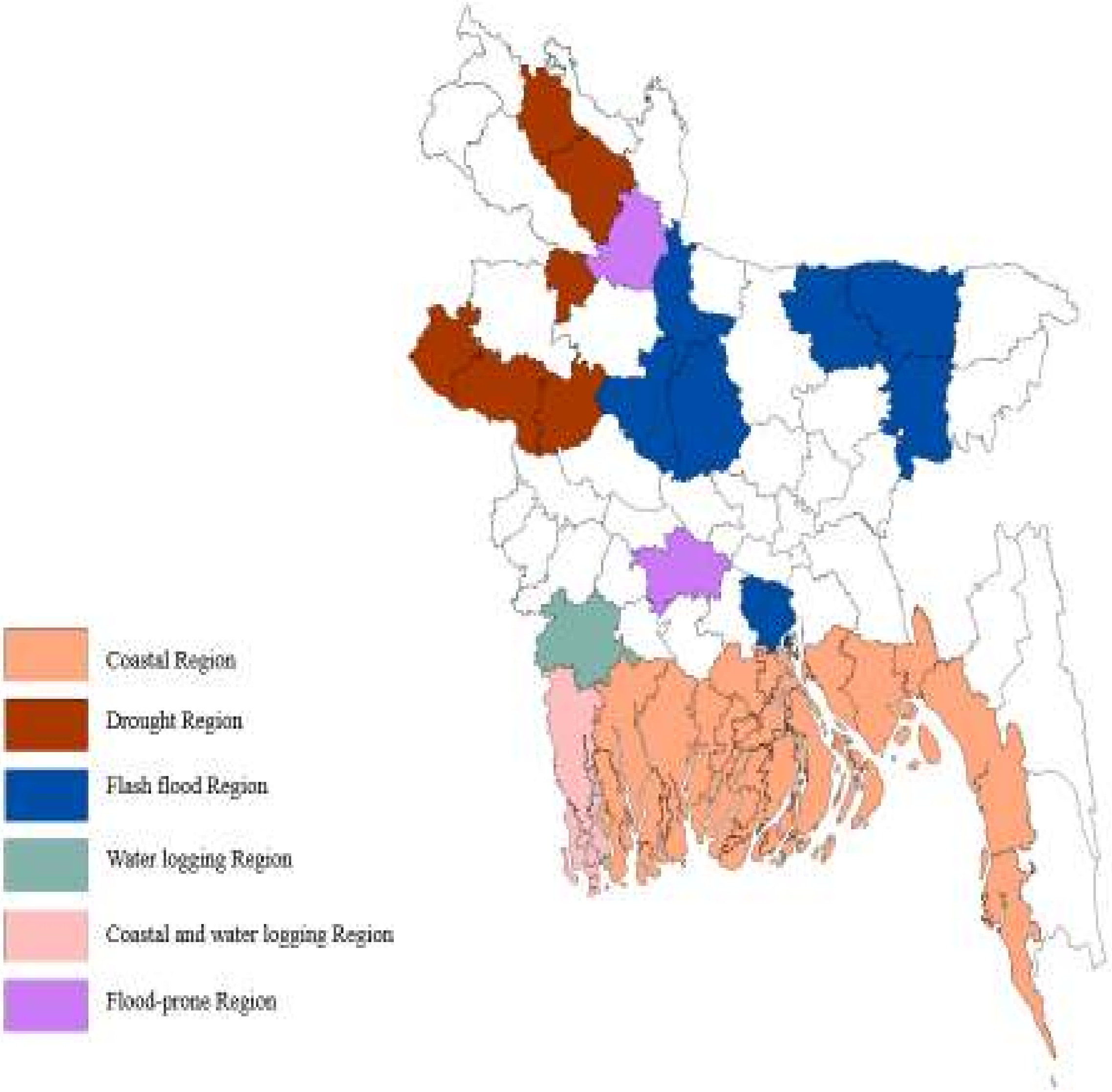
The National Food Policy (NFP 2006) nominated food security as a major concern, and the main goal of the 7th Five Year Plan (2016-2020) is to accelerating growth (average real GDP growth rate of 7.4% per year) including empowering citizens and reduction in extreme poverty in order to ensure dependable food security for not only national but also for household/ individual levels at all times (GoB, 2015c). However, Bangladesh has already made some progress by achieving average GDP growth around 6.3 percent per year during the

6th Five Year Plans over the period of 2011-2015, but the incidence of malnutrition is still a major challenge for ensuring a balanced diet for all (GoB, 2015c; FAO, IFAD and WFP, 2014). The problem is acute in Bangladesh due to a small land area of only 148 million hectares for a population of 156.6 million (2013). Hence, the density of the population is about 1,016 per square kilometer (Mainuddin, 2015). Bangladesh is rated as under great threat of climate change (Maplecroft 2014), and many of the adverse impacts of climate change will be imposed as an additional threat to the food and agricultural sector (Muller, 2011).

In Bangladesh over six percent of the population is affected by different types of natural disasters each year, which makes it one of the most vulnerable countries in the world. Between 1980 and 2013, the average Bangladeshi was personally affected by two disasters because of its geographical location. The primary threats to Bangladesh can be characterized as high temperatures, floods, droughts, cyclones and sea-level rises due to climate change. The risks from floods, droughts and sea level rises, all potentially impact the sustainability of rice yields. Over the last 30 years, nearly 200 of these climate-related disaster incidents occurred in Bangladesh. As a result of these disasters, homes and livelihoods were destroyed, thousands of people died, costing the nation around $16 billion in damages and economic losses (The Asia Foundation Report, 2012; Give2Asia and IIRR, 2016).

There are three major food security challenges for Bangladesh. These are adverse climate change, high population density, and shortage of lands. These challenges pose significant and increasing threats on agricultural production.

Figure 1: Natural Disaster Prone Districts in Bangladesh



The northwest part of the country is highly prone to drought and inadequate irrigation. While the southeast part, mostly the part of coastal belts experiences the consequences of sea level rise, which results in salinity of soils and rivers, and flood resulting from heavy rainfall. In the central region, annual flooding occurs due to stronger monsoons. These obstacles will affect farmers and have negative and significant effects on national food self-sufficiency (Denissen, 2012).

Across all regions and disasters, it is the poor and marginalized population, particularly women and girls, who suffer the most. Those living on small offshore islands (chars), indigenous people, and poor communities engaged in climate-sensitive livelihoods, are also acutely affected because when disaster strikes, they become even poorer and are forced to move to even more vulnerable areas in search of lower costs of living. Even though the GoB, international agencies such as the United Nations (UN) and the World Bank (WB), and international non-governmental organizations (INGOs) and local NGOs have been working for decades to prepare for disasters and mitigate the effects of climate change, significant challenges remain.

1.2 Bangladesh Agriculture: Rice

Production

Most agricultural production in developing countries like Bangladesh is highly dependent on climate. Bangladesh has a high population density, and 26.2% of its population lives below poverty level[1]. In addition, approximately 66% of the total population derives their livelihoods from agriculture (BBS, 2014). Bangladesh is the sixth-largest rice producer in the world (Bishwajit et al., 2013 and IRRI, 2015). Rice accounts for about 94% of the total food grain production (HIES 2010, Hossain et al., 2005).

In Bangladesh, farmers produce rice over three seasons (Aman, Boro, and Aus) throughout the year in order to ensure food availability for the continually increasing population (see Figure 2). Aman and Boro seasons are the two main rice crops because of higher yields during 2004-2014, while Aus has the lowest yield involving traditional strains

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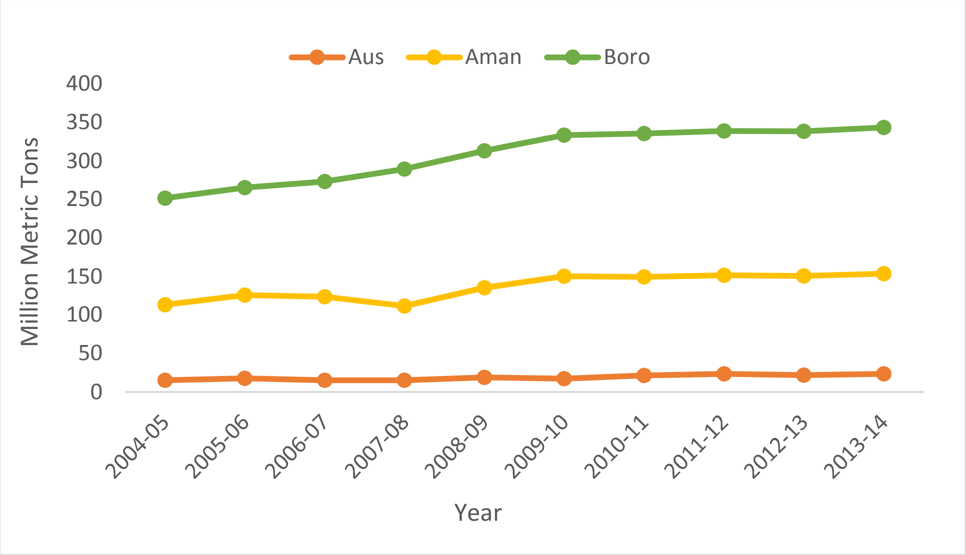
[1] The poverty level or poverty threshold is the minimum level of income less than $1.25 a day, or a diet of less than 2,100 calories daily in Bangladesh (GoB, 2015a).

(see Table 1). Aus and Aman are rain-fed monsoon crops whereas Boro is an irrigation intensive season, grown during the winter season (Rahman and Parvin, 2009). Among the total irrigated area for rice about 84.3% used for Boro cultivation (BBS, 2014). Indeed, Bangladesh rice production is dominated by Boro rice and a majority of the yields come from Rabi season, accounting more than 60% of the total rice production (MoFDM, 2012; Alam and Islam, 2013).

Figure 2: Trends of Rice Production in Different Seasons



Source: BBS, 2014

Table 1: Different growing seasons for rice production

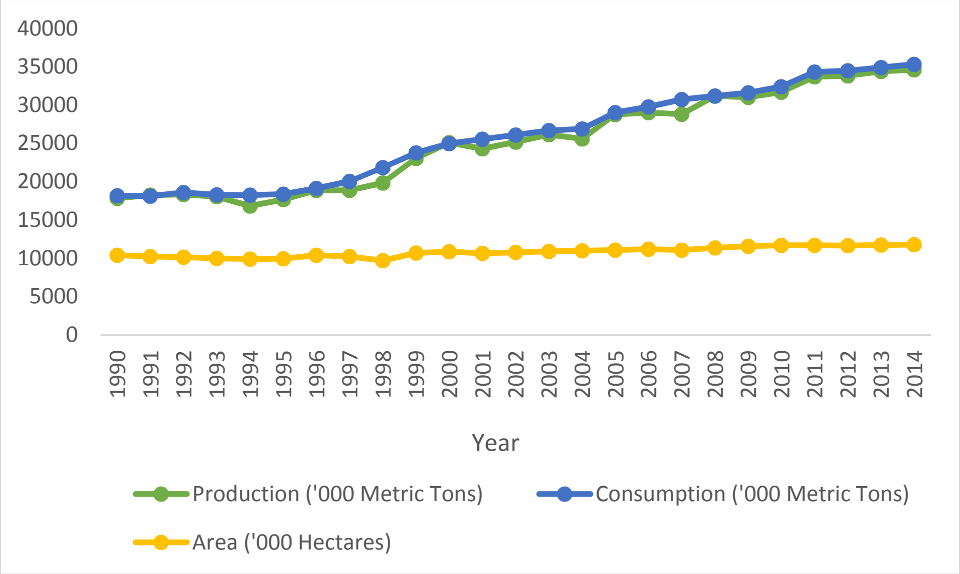
Rice Season	**Month**	**Season for Growing Rice**
Aus	March – July	Pre-monsoon (Kharif-I)
Aman	June – November	Monsoon (Kharif-II)
Boro	November – May	Winter (Rabi)

Agriculture contributes to 15.59% of the national GDP and employs about 47% of the total labor forces (BBS, 2014; HIES, 2010). The source of livelihood for two-thirds of

Bangladeshi farmers is related to rice production, which accounts for around three-fourths of the cultivated area and 74.75% of the total irrigated area involved in rice cultivation (BBS, 2014). Most farm households are involved with marginal (0.21 to 0.5 ha) and small (0.51 to 1 ha) farming with about 71% of households living on 0.021 to 1 hectares of cultivable land while average farm size is 0.5 hectares in Bangladesh (IAPP, 2013). Rice cultivation is a multi-faceted activity that is labor-intensive, characterized by low technology and low capital investments in small scale agriculture of Bangladesh.

The rice sector accounts for almost 50 percent of the agricultural GDP and about 15 percent of the national income in Bangladesh. Among all households engaged in the agriculture sector, nearly 13 million of these farm families produce rice (BRKB, online). Bangladesh accelerated its rice production after independence in 1971 to 2010 by 10.97 to 33.53 million metric tons (USDA, online). However, according to the Food and Agricultural Organization (FAO) and the United Nations Development Program (UNDP) rice grows over almost 10.27 million hectares out of the 13.8 million hectares of arable land (UNDP and FAO, 1988; Hossain and Deb, 2003). As shown in Figure 3, in 2014, rice was planted on 11.80 million hectares of land and production about 34.6 million metric tons.

Figure 3: Trends of Rice Production, Consumption and Area in Different Years



Source: United States Department of Agriculture (USDA online), and BBS 2014

Consumption

According to FAO, Bangladesh ranks 4th in per capita rice consumption in the world. The average per capita consumption of rice is approximately 217.8 kg/day in 2010-11 to 215.5 kg/day in 2014-2015 and projected to be 210.9 kg/day during 2021-22 (Wailes and Chavez, 2012). Rice is the staple food item for the 150.6 million population of Bangladesh and contributes to about 62% of per capita daily calorie intake, which is one of the highest in the world (World Bank, 2013; HIES, 2010). However, for an average Bangladeshi, one-half of the total protein intake comes from the consumption of rice also (Hossain et al., 2005; Thorne-Lyman et al., 2010).

HIES (2010) data indicate that about 60 percent of households expend 75 percent or above of their total expenditures on food for rice in Bangladesh. Despite the production growth, the country is still importing around 1 to 5 percent (1.2 million metric tons during 2014/15) of rice to meet its consumption requirements (USDA-Grain and Feed Annual, 2016). Furthermore, because of the growing population, rising food demand makes the situation worse. Under the SDGs, Bangladesh is trying to achieve sustainable agricultural production for national self-sufficiency in food grains, particularly for rice by 2030.

Market

Food price instability has become the major issue for most of the developing countries' households because it generates unpredictability of food price in the market. Bangladesh is a developing country where a large increase in food price has negative effects on millions of low-income population (FAO, IFAD and WFP, 2014). Food price volatility is influenced by many factors such as agriculture and energy policies, supply disruptions for key inputs such as fertilizers, commodity prices and market speculation, extreme weather changes, rising global demand, falling surplus stocks, and instability in international food markets.

The domestic supply (including domestic production plus imports) and domestic demand of rice (demand by the producer, consumer and government) helps to determine the market rice prices in Bangladesh. Moreover, the world market price of rice influences the domestic market price in Bangladesh only through the government food policy. Liberalization of trade policy has made the relationship between domestic market price and world price effective (Alam et al, 2012; Dorosh, 1999). Afterwards, a surge in the world price during2007-2008 helped the producers, nonetheless in case of a net rice importer country like Bangladesh, benefits of free trade can be eroded where majority of the households (76.8 percent) are actually net consumers (Zezza et al., 2008; Alam et al, 2012).

The GoB needs to take into consideration the vulnerability in food production and price volatility before embarking on any new rice. Therefore, typically the dual challenge for the government is to maintain rice prices within an affordable limit to protect the net consumers when their purchasing power is reduced and also keep fair prices for the net producers in order to protect both of them.

To maintain food security (via price stability and food price risk management) of those who depend on the markets for their consumption, policies should be carefully designed because the world market price is more volatile and influences domestic prices (Alam et al., 2012). This presents a tremendous challenge to Bangladesh which needs to have detailed information about the socioeconomic consequences of rice farmers for further policy making and for ensuring their welfare.

1.3 Policy

Food Policy

Bangladesh is the world's seventh-most-populous country in the world (Farid et al., 2011; UN, 2009). The demand for efficient food production, distribution, and consumption for the Bangladesh population will increase, especially for rice as a staple food grain. In order to meet food demand, the government has to put the agriculture sector as its topmost priority.

The GoB designed and approved the National Food Policy (2006) and the National Food Policy Plan of Action (2008-2015). These policies led to a package of incentives to keep the farmers in rice production and also to provide cereals to the consumers at an affordable price. One of the major incentives is to ensure income support to farmers, and thus the government provides a support price higher than the cost of production in order to ensure farmers' profit. Indeed, as described in the National Food Policy (2006), small producers need adequate incentives to produce, as their economic status often compels them to sell immediately after harvest when prices are low. On the other hand, the producer needs to purchase as a consumer when the rice price is higher later in the season. Higher prices, however, are in conflict with the objective of keeping prices low enough so that the low-income consumers can afford to buy food.

The silent threats of climate change have direct and indirect effects on agricultural production and households' access to food. Therefore, the GoB has formulated a number of policies as safeguards targeting the threats to food security, such as 'Vision 2021'[2]. The negative impacts of climate change will hinder crop production to achieve the targets of 'Vision 2021'. In 2009, assigning climate change as the topmost concern, Bangladesh has developed a Climate Change Strategy and Action Plan (BCCSAP). The plan determined six thematic areas, among them food security, social protection, and health ranked the highest, which indicates that the country needs to be not only self-sufficient in terms of food production, but also manage equitable distribution of nutritious food. Consequently, the Climate Change Trust Fund (CCTF) was created by the Government in 2009-10 from its own resources in order to reduce vulnerabilities caused by the adverse effects of climate change with the allocation of US$ 400 million during the last seven fiscal years (2009-2010 to 2015-16) (BCCT, online).

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[2] The main goal of 'Vision 2021'is to become a middle income country through identified eight goals where poverty will be completely eradicated by the year 2021 when Bangladesh will be celebrating 50 years of independence (CPD, 2007).

Food Self Sufficiency

According to FAO estimates, 26% of the population is undernourished in Bangladesh (IFAD, WFP and FAO, 2011). Furthermore, above 45% of rural households and 76% of urban households are suffering from inadequate calorie intake (FAO, 2011). As a matter of fact, many people within this country have an insufficient diet and suffering from periods of food shortage.

The GoB gives food security the highest importance by setting targets of self-sufficiency on rice production by 2030 as a part of SDGs, which will satisfy domestic demand. The inclusive objective of agricultural policy in Bangladesh includes not only a substantial acceleration in domestic food production but also a decreased dependence on or elimination of food import/aid in the long term. However, natural disasters can disrupt crop production, leaving consumers dependent on the international market and the government buffer stocks to ensure food security. The country needs to undertake precautionary measures to ensure food security in disaster years such as increasing the level of current production as well as food stocks and stabilizing year-to-year variation.

The effect of population growth and climate change presents the country with enormous challenges, especially for food production and arable land use. Approximately two-thirds of the land area is less than 5 meters above sea level, which makes the country one of the most flood-prone countries in the world (Dasgupta et al., 2015). Climate change seems likely to hit hardest the farm households in this region because they are more heavily dependent on nature. With the threat of climate change adversely impacts agriculture, food security is a key issue in Bangladesh given the growing population.

1.4 Justification of the study

Bangladesh is situated between the Himalayas and the Bay of Bengal, and the country is very prone to natural disasters (World Bank, 2000). Bangladesh has been identified as highly vulnerable to the effects of climate change, because much of the land is low-lying and very flat making crop production susceptible to flooding and sea level rise. It is expected that the intensity and frequency of storms events, irregular rainfall, high temperatures, flash floods, incursion of salinization, and droughts will increase and intensify due to the effects of global warming (The Asia Foundation Report, 2012).

Rice is particularly vulnerable because it is grown in the low-lying coastal regions. These low-lying regions are vulnerable to rising sea levels and changes in weather patterns which could lead to a substantial decline in productivity of rice farms. Therefore, the negative effects of climate change on rice production have the potential to impact rural households who depend mostly on agricultural income and to impact the government's ability to achieve food security. This could lead to increased food insecurity and higher levels of poverty, especially for the poorest and most vulnerable. Indeed, whatever improvement Bangladesh has achieved in agricultural production is highly vulnerable because the climatic shocks make achieving environment sustainability challenging.

Geographically, Bangladesh is under great threat of global warming because it is situated in the tropical region (FAO, 2011). Bangladesh is located in the northeast region of the Indian subcontinent on the Bay of Bengal. It is a predominantly low-lying country with several major rivers located mainly in the large delta formed by the Brahmaputra and Ganges Rivers. According to Intergovernmental Panel on Climate Change (IPCC), the sea level of the Bay of Bengal will rise by about 1 meter this century, consequently a large portion of coastal land will be submerged under water. These features make Bangladesh vulnerable to natural disasters and the high levels of poverty makes the situation more challenging (Mahmood, 2012). Bangladesh is facing some other natural disasters because of climate change, like extended rainy seasons and summer are more prolonged which means it is more humid and hotter during summer. By the year 2030, the temperature is projected to be 0.5 to 0.2°C warmer than it is today. The duration of the winter season is shortening (Kafiluddin, 2005; Mahmood, 2012).

According to the World Risk Index (2011) Bangladesh is ranked 6th among the most vulnerable countries to natural disasters, and ranked 2nd among the Asian countries (Kreft et al., 2015). Being one of the most affected and susceptible countries of the world, crop production as well as food security will be jeopardized because of disappearing diversified seasons, natural disasters like increasing salinity in coastal zones, flood in the central zone and drought in northern areas (Denissen, 2012). Food insecurity is a major problem in Bangladesh. Food production and marketing systems need to be efficient across the country to minimize food insecurity problems at the national level. This study examines the utility of food consumption from farmers own production through a budget constraint and the market demand for rice at the national level.

1.5 Objectives of the study

The objective of this paper is to develop a farm household rice production model to quantify the ex-ante impact of potential land loss and yield reduction for climate change on consumption, production, prices, farmers' welfare, and the government's ability to achieve self-sufficiency in rice production.

1.6 Organization of Thesis

The structure of this thesis is as follows. The first chapter highlights the overall importance of agriculture and rice, government policy, importance of the study, and objectives of this research. The second chapter focuses on the effects of climate change on rice production and arable land from review of the relevant literatures especially with respect to the methods and findings. The third chapter describes the method of formulating the farm household model for rice in Bangladesh, the study data used; and the methods used to evaluate the model's parameters according to the data. Furthermore, this chapter presents the results of the climate change effects on productivity of rice and land through model simulation. Finally, in the fourth chapter some policy guidelines are presented to evaluate how the GoB can cope with the adverse effects of climate change.

Chapter 2: Literature Review

The main purpose of this literature review is to explore how climate change affects the total production and total area of rice and then to determine how natural disasters impact household food security in Bangladesh. Several of the studies address different aspects of climate change in rice production as well as the impact on food security. The studies were conducted in different countries of the world including Bangladesh. The first section reviews different papers focusing on rice production and subsistence farming in Bangladesh. The second section reviews studies on the impact of climate change on rice production and arable land. The final section considers the gaps in the existing literature due to the impact of climate change on Bangladesh agriculture.

2.1 Rice Production and Subsistence Farming in Bangladesh

Hossain et al. (2005) found that domestic food grain production remains susceptible to floods and droughts, and the availability of other foods has not increased. About 40% of the population live below the poverty line, and income inequality has been worsening. However, Barua and Alam (2000) reported that the price instability was higher than the area and yield instability for all the crops studied. The extent of real price fluctuations was higher relative to area, production, and yield fluctuation of all the crops studied. Yield of other crops (wheat and jute) had a significant influence on the post-harvest price determination of rice varieties as revealed by the price flexibility coefficients.

Van Wijk et al. (2012) reviewed some literature to assess how applicable the farm and farm household models are used to evaluate food security in relation to adaptation of climate change, mitigation, and management of risk. They reviewed about 16,000 research papers focusing on more than a 1000 models. However, this systematic review found that some of the models used climate as an input whereas only a few studied climate change adaptation or mitigation at the farm level. They argue that more explicit analysis on adaptation, vulnerability, and risk at the farm level is needed. The general overview of this review study is that there are enough integrated techniques of farm systems to evaluate climate change, adaptation and mitigation, but still these techniques need to be applied to make it meaningful to the decision makers of the farm.

2.2 Climate Change and Rice Production

Agricultural production stability is a major concern to meet the sustained increase in demand for staple foods. However, stability in food production faces a growing threat from climate change. Chen et al. (2012) observed that climate change has already had a negative impact on Asia through extreme temperatures, frequent flooding and droughts, sea level rise, and increased salinity of water supplies in rain-fed agricultural areas. By using a partial equilibrium global rice trade model, they found the potential impact of sea level rise combined with the climate change on global rice production and price. The authors predicted 1.6% to 2.73% reduction in global rice production, followed by an estimated 7.14% to 12.77% rise in global rice price. The study also revealed that many key rice consuming countries, including Bangladesh, Egypt, Japan, Myanmar, and Vietnam are expected to be among the hardest hit by the effects of sea level rise (Chen et al., 2012, Nelson et al., 2010). Dasgupta et al. (2009) identified ten developing countries whose land areas are most exposed to the potential threat of a one-meter rise in sea level. The most affected countries are Bangladesh, China, Taiwan, and Vietnam, which are the major rice-growing as well as rice-consuming countries in the world.

Sarker et al. (2012) analyzed the impacts of climate change on rice production and farmers’ adaptation to climate change in Bangladesh. National aggregate level data were used to examine changes in maximum temperature, minimum temperature, and rainfall over the past 60 years. Furthermore, the author also implemented a disaggregated analysis to assess the effects of climate change on the yield and variability of Aus, Aman, and Boro rice production using cross-sectional time series (panel) data. The results revealed that the maximum temperature is an increasing risk for Aus and Aman rice yields while it is a decreasing risk for Boro rice yield. Finally, rainfall was significant only for Aus and Aman rice, with a positive impact on output for both seasons (Sarker et al., 2012). However, this study did not account for regional variations and unobserved heterogeneity.

Karim et al. (1996) assessed the vulnerability for high yield varieties of rice at three different levels of CO_2 concentration and two levels of temperature increase. The authors found that yields can be increased with the combination of higher concentrations of CO_2 and unchanged temperature. Higher temperatures which account for a 4^oC increase negatively affected yields in almost all study locations and for all seasons for both rice and wheat.

Ali (1999) analyzed the impact of climate change on rice yield in Bangladesh which focused on the maximum temperature which is statistically significant and negatively affects the yield of all three rice crops (Aus, Aman, Boro). In contrast, minimum temperature is highly significant and has a positive impact on the yield of Boro rice only. However, the effects of maximum temperature and rainfall are more prominent compared to the effects of minimum temperature and humidity on rice yields in Bangladesh.

Basak et al. (2010) assessed the susceptibility of Boro rice production due to the impacts of climate change. They focused on increasing maximum and minimum temperatures by 2°C and 4°C respectively and adjusting different level of CO_2 concentrations (50 ppm, 100 ppm and 200 ppm). A 4°C increase in temperature would reduce rice yields drastically by 22.9%, whereas a 2°C increase in temperature would reduce yields by 10.4%. However, increasing the concentration of CO_2 is likely to have some positive effect on rice yield but is not so significant compared to the negative effect of temperature.

World Bank (2000) estimated that increased salinity from a 0.3 meter sea level rise will cause a net reduction of 0.5 million metric tons of rice production (Hossain, 2010). The Global Circulation Model (GCM) results predict an average temperature increase in Bangladesh due to climate change of 1°C by 2030 and 1.4°C by 2050 (IPCC,2007). In an investigation of impacts on a coastal village it was found that rice production in 2003 was 1,151 metric tons less than in 1985 (a loss of 69%). About 77% of rice production decreased due to conversion of rice fields into shrimp ponds and 23% was because of yield loss (Ali, 2006).

Clarke et al. (2015) developed a simulation model for soil water balances, dry season irrigation requirements and the effectiveness of the monsoon season rainfall. Simulations were run using historical climate data from 1981 to 2098 based on the Met Office Hadley Centre HadRM3P regional climate model. This study carried out in the Barisal district indicates that irrigating with water at up to 4 parts per thousand (ppt) can be sustainable but when the salinity goes above 5 parts per thousand (ppt), the monsoon rainfall is no longer able to leach the dry season salt deposits. Results show that the dry season is expected to be 2–3 weeks longer by the end of 21st century than it was in 2014. Expectations of sea level rise and additional saline intrusion into ground water aquifers mean that salinity increases in dry season irrigation water in the coastal area which affects the farm productivity to decrease by as a much as 50%, threatening the livelihoods of farmers in this region (Clarke et al., 2015).

Recently, Yu et al. (2010) and Ruane et al. (2013) assessed climate change impacts on crop yield by incorporating both climate and water resources parameters. The results show that by the 2050s yields of the major monsoon season crop (Aus and Aman rice) will not be impacted by climate change, while Boro (irrigated) rice would suffer more immediate effects of climate change and yields might be reduced by about 5%. The yield of monsoon rice in Nachole in Bangladesh is projected to increase by about 3% under all the emission scenarios (A2, A1B, B1) as the negative impact of changes in temperature and precipitation are offset by the increase of carbon fertilization. Yu et al. (2010) estimates that overall rice production in Bangladesh will be reduced by an average of 7.4% every year over the period 2005–2050 due to the adverse effects of climate change.

Thurlow (2012) explained that the effects of climate change in Bangladesh are likely to be higher temperatures throughout the year and problems with rainfall predictability, leading to greater water shortages in some seasons and flooding in others. Some studies predict that rainfall will increase in the wet monsoon season and decrease in the dry winter and spring months (Shahid 2010; Thurlow et al., 2012). Thurlow et al. (2012) predict that climate change may reduce winter season Boro rice (irrigated) production more than wet season Aus and Aman rice production. According to the World Bank, a 1 meter rise in sea level will reduce rice production by 50%. This reduction will cost $3.5 billion at the then current market price (Uzzaman, 2014). Another World Bank (2000) study suggests that increased salinity alone from a 0.3 meter sea level rise will cause a net reduction of 0.5 million metric tons of rice production (Hossain, 2010).

2.3 Climate Change and Land

Table 2: Bangladesh Agriculture at a Glance

Items	**Quantity**
Total Area	14.84 million hectare
Forest	2.59 million hectare
Cultivable land	8.44 million hectare
Current fellow	0.46 million hectare
Single Cropped Area	2.85 million hectare
Double Cropped Area	3.98 million hectare
Triple Cropped Area	0.97 million hectare
Net cropped area	7.80 million hectare
Total cropped area	13.74 million hectare
Total food crop demand	23.02 million metric ton
Total food crop production	27.78 million metric ton
Net production	24.56 million metric ton

Source: Ministry of Agriculture (MoA), 2012

The total cultivable land in Bangladesh is small compared to the total population. According to the Ministry of Agriculture, the total cultivable land area is 8.44 million hectares (see Table 2) which means per capita cultivable land is about 0.08 hectares only, which is one of the lowest per capita cultivable land holding in the world (Anik et al., 2012; SHED, 2012). The sea level rise is the most important problem that leads to a loss of agricultural land in Bangladesh. With a sea level rise of 1 meter, Bangladesh could lose up to 18% of its landmass including half of its rice land which could directly make 11% of the country’s population food insecure (Ali, 2000). The International Panel on Climate Change (IPCC) predicted that by 2050, Bangladesh is on course to lose 17% of total land which could affect 30% of its food production and as a result 30 million Bangladeshis could become climate refugees, and consequently the poverty will increase (Mahmood, 2012; Planetizen, 2008). The Prime Minister of Bangladesh Sheikh Hasina stated that more extreme estimations of 1meter rise in the sea level would submerge 25% of landmass (Mahmood, 2012; News Today, 2011). However, 40% of Bangladesh's productive land is projected to be lost in the southern region because of a 65cm sea level rise by the 2080s (World Bank, 2013).

Moreover, agricultural land has been decreasing by about 0.26% annually from 1976-77 to 2010-11 (a 34-year average) (Hasan, et al. 2013). According to Nicholls and Leatherman (1995), a 1 meter sea level rise would affect 6 million people in Egypt, with 12% to 15% of agricultural land lost; 13 million in Bangladesh, with 16% of national rice production lost; and 72 million people in China, with 10,000 hectares of agricultural land lost.

The World Bank (2000) estimated that 10 cm, 25cm and 1 meter rise in sea level by 2020, 2050 and 2100; would eliminate 2%, 4% and 17.5% of total land mass, respectively (Sarwar and Wallman, 2005). Alternatively, World Bank also projects that the average temperature will increase by 2^{o}C, and sea levels will rise by 50 centimeters in Bangladesh by the year of 2050 which could submerge a portion of the coastal area in Bangladesh. Furthermore, 30% of the cultivable land is in the coastal area, and most of the area is less than 10 meters above sea level which makes Bangladesh highly vulnerable to rising sea levels. About 2,500, 8,000 and 14,000 square km of land (2%, 5% and 10%, respectively) of the total land area will be lost by the year of 2050 due to the sea level rises of 0.1 meter, 0.3 meter and 1.0 meter, respectively, in the country (Ali, 2000; Hossain, 2010).

2.4 Contribution to Literature

Most of the previous studies have focused on climate change impacts due to some weather parameters for example temperature, rainfall and CO_2 emission on rice production.

But very few studies focused on the impact of climate change on household welfare. No studies focus on the rice farmer's welfare in Bangladesh due to the impacts of climate change if arable land and rice productivity decrease together. Therefore, this study is an exploration of the impact of climate change on rice production and consumption, on non-rice agricultural production and consumption, an on the prices and incomes of the rice farmers using a farm household model.

Chapter 3: Methodology and Results

3.1 Farm Household Model: Bangladesh Rice Production

In this model, a representative rice farm household maximizes utility with respect to consumption of rice, non-rice agricultural products, manufactured items, and leisure subject to their budget constraint, total time availability, and an unemployment constraint. The farmer produces two agricultural goods (rice and non-rice agricultural crops) using variable inputs (fertilizer and pesticides), land, and labor. The farmer earns income from not only rice and non-rice agricultural production, but also off-farm employment. The variable input prices are fixed, while the rental rate of land and the price of rice are endogenously determined in equilibrium.

The total available time of the households is dedicated to working on the farm, working in non-farm labor markets for additional income, and leisure. The consumption of rice and non-rice agricultural crops by non-agriculture consumers is represented by a demand function.

Assumptions for Labor Market

Total time spent working on the farm ($\bar{l}$) is less than the total available time (l), i.e., $\bar{l} < l$; which implies that the farmer does not hire labor and has extra time to sell in the labor market (l_m) after producing on their own farm, $l_m > 0$.However, because of the fixed minimum wage($\bar{w}$) for low-skilled workers, the labor market cannot absorb all of the time the farmers wish to spend in non-farm employment, which leads to unemployment. Assuming the unemployment constraint is binding, production and consumption decisions are not separable. Unemployment in the labor market implies that farmers would like to work in urban employment in order to get higher wages but urban labor market cannot absorb all farmers.

Therefore, farmers try to spend more time in farm activities and leisure than what would otherwise be optimal. This implies consumption and production decisions are made simultaneously, which breaks the separability condition of the standard farm-household model.

Assumptions for Land

Land is rented by the farmer and employed in rice and non-rice agricultural goods. All productive land is used for rice and non-rice agricultural production. Thus, land supply is inelastic which means supply will not increase or decrease in response to changes in price.

The Aggregate Rice Farm Household Model

The average farmers derives utility from the consumption of rice c_r, non-rice agricultural goods c_a, manufacturing goods c_m, and leisure c_l based on the Cobb-Douglas utility function. The consumer's problem is

$$\max_{c_r, c_a, c_m, c_l} (c_r - d)^{\alpha_1} (c_a)^{\alpha_2} (c_m)^{\alpha_3} (c_l)^{\alpha_4}, \tag{1}$$

where d is the minimum (subsistence) amount of rice that must be consumed to survive and $\alpha_1 - \alpha_4$ are their respective consumption shares parameters, subject to the budget constraint

$$p_r c_r + p_a c_a + p_m c_m \leq p_r y_r + p_a y_a + w l_m, \tag{2}$$

where p_r represents the price of rice, p_a is the price of non-rice agricultural goods, and p_m is the price of manufacturing goods. The subsistence requirement d satisfies Engels Law, which implies that the income elasticity of demand is less than unity and as income increases, a smaller portion of income is spent in rice consumption. The left-hand side of equation (2) is expenditures on consumption goods and the right-hand side is income from rice production, non-rice production, and time spent working in non-farm activities (wl_m).

Rice production is represented by the constant elasticity of substitution (CES) production function:

$$y_r = f(l_r, x_r, h_r; z_r) = z_r\left(\beta_1 l_r^{\eta} + \beta_2 x_r^{\eta} + \beta_3 h_r^{\eta}\right)^{\frac{\mu_r}{\eta}} \tag{3}$$

where $y_r$is the total yield from rice production, $z_r$is the productivity parameter, l_r represents labor used, $x_r$are other inputs (fertilizer and pesticides)used, h_r is land used for rice production, β_is are the share parameters of the three input variables, and η is the elasticity of substitution parameter.

Non-rice agricultural production also follows the CES production function:

$$y_a = g(l_a, x_a, h_a; z_a) = z_a\left(\gamma_1 l_a^{\eta} + \gamma_2 x_a^{\eta} + \gamma_3 h_a^{\eta}\right)^{\frac{\mu_a}{\eta}} \tag{4}$$

where y_a is the total yield from non-rice production, z_a is the total productivity of non-rice agricultural goods, l_a is total hour of labor used, x_a is other inputs (fertilizer, pesticides) used, h_a is the total amount of land used for non-rice agricultural production, γ_is are the share parameters of the three input variables respectively, and η is the elasticity of substitution parameter.

Total available time to the household is

$$\bar{l} \geq c_l + l_r + l_a + \, + l_m, \tag{5}$$

which indicates that total labor hours available in a year $\bar{l}$ consists of family labor used in rice production l_r , family labor used in non-rice agricultural production l_a, time spent working off-farm l_m, and leisure c_l.

The labor unemployment condition is

$$L \leq l_m, \tag{6}$$

which indicates that the total amount of labor the market can absorb L is less than the total time the farmer would like to sell in the market l_m. The farmers want to sell more labor in the market, but the market cannot absorb all which leads to the farmer spending more time working on the farm or at leisure than what is otherwise optimal.

Solving for l_m in equation (5) and substituting into equation (6) yields the labor unemployment condition

$$L \leq \bar{l} - c_l - l_r - l_a. \tag{7}$$

Next, the market clearing condition for rice, non-rice agricultural products, and land is presented.

The price of rice is determined through the market clearing condition.

$$y_r + \delta_I {p_r}^{\epsilon_I} = c_r + \delta_D (p_r)^{-\epsilon_D} + \delta_G (p_r)^{-\epsilon_G} \tag{8}$$

where total rice supply (left-hand side) is equal to the total demand (right-hand side). Total supply is total domestic production y_r plus imports from the rest of the world (ROW) represented by the supply function $\delta_I {p_r}^{\epsilon_I}$ where, δ_I is the scale parameter and ϵ_I is the elasticity of export supply by the ROW. Total demand is total farm rice consumption c_r plus non-farm (or urban) rice consumption represented by the demand function $\delta_D (p_r)^{-\epsilon_D}$ where, δ_D is the scale parameter and ϵ_D is elasticity of demand plus government purchases for rice given by the demand function $\delta_G (p_r)^{-\epsilon_G}$.

The price of non-rice agricultural goods is determined by the market clearing condition

$$y_a = c_a + \sigma_a(p_a)^{-\rho_a} \tag{9}$$

where total supply (y_a) equals total demand means total farm non-rice consumption c_a plus urban non-rice consumption represented by the demand function $\sigma_a(p_a)^{-\rho_a}$ where σ_a is the scale parameter and ρ_a is elasticity of demand.

The market clearing condition for land is

$$H = h_r + h_a, \tag{10}$$

where the total amount of land available in the country H is equal to the land used for rice production h_r and land used for non-rice agricultural production h_a.

3.2 Social Welfare

Given the leisure is an argument to utility, we measure social welfare using the consumption equivalent metric. Suppose $c_r^b, c_a^b, c_m^b, c_l^b$ is consumption in the baseline before climate change and $c_r^a, c_a^a, c_m^a, c_l^a$ is consumption in the alternate scenario after climate change has occurred. The consumption equivalent g or the factor change in welfare solves:

$$(c_r^b - d)^{\alpha_1} (c_a^b)^{\alpha_2} (c_m^b)^{\alpha_3} \left(c_l^b\right)^{\alpha_4} = (gc_r^a - d)^{\alpha_1} (gc_a^a)^{\alpha_2} (gc_m^a)^{\alpha_3} (c_l^a)^{\alpha_4} \tag{11}$$

Notice that g only accounts for changes in consumption good while ignoring any changes in leisure. The consumption equivalent metric g is interpreted as the percentage increase (or decrease) in rice, non-rice food, and manufacturing goods consumption in the alternate scenario need for the farm household to be as well off as in the baseline consumption allocation.

3.3 Lagrangian, First-Order Conditions, and System of Equations

The Lagrangian for maximizing utility (equation 1) subject to the full-income constraint (equation 2) is

$$\begin{aligned}\mathcal{L} = \{\, (c_r - d)^{\alpha_1} {c_a}^{\alpha_2} {c_m}^{\alpha_3} {c_l}^{\alpha_4} \; + \; \lambda_1 \{ (p_r z_r \big(\beta_1 l_r^{\eta} \; + \beta_2 x_r^{\eta} \; + \; \beta_3 h_r^{\eta}\big)^{\frac{\mu_r}{\eta}} \\ + p_a z_a \big(\gamma_1 l_a^{\eta} + \gamma_2 x_a^{\eta} + \gamma_3 h_a^{\eta}\big)^{\frac{\mu_a}{\eta}} - P_x(x_r + \; x_a) - p_h(h_r \; + \; h_a) \\ + w\big(\bar{l} - \; c_l - \; l_r - l_a\big) - (p_r c_r + p_r c_r + p_m c_m)\} + \; \lambda_2 \, (L \\ - \big(\bar{l} - \; c_l - \; l_r - l_a\big) \,\} \end{aligned} \tag{12}$$

Taking the partial derivatives ($\frac{\partial \mathcal{L}}{\partial n}$) with respect to the *nth* argument ($n = c_r\,, c_a, c_m,\; c_l, l_r,$ $x_r, h_r,\; l_a, x_a, h_a, \lambda_1, \lambda_2$) and setting them equal to zero yields the first-order conditions:

Consumer:

$$\frac{\partial \mathcal{L}}{\partial c_r} = \alpha_1 (c_r - d)^{\alpha_1 - 1} {c_a}^{\alpha_2} {c_m}^{\alpha_3} {c_l}^{\alpha_4} - \lambda_1 p_r = 0 \tag{13}$$

$$\frac{\partial \mathcal{L}}{\partial c_a} = \; \alpha_2 (c_r - d)^{\alpha_1} {c_a}^{\alpha_2 - 1} {c_m}^{\alpha_3} {c_l}^{\alpha_4} - \lambda_1 p_a = 0 \tag{14}$$

$$\frac{\partial \mathcal{L}}{\partial c_m} = \; \alpha_3 (c_r - d)^{\alpha_1} {c_a}^{\alpha_2} {c_m}^{\alpha_3 - 1} {c_l}^{\alpha_4} - \lambda_1 p_m = 0 \tag{15}$$

$$\frac{\partial \mathcal{L}}{\partial c_l} = \; \alpha_4 (c_r - d)^{\alpha_1} {c_a}^{\alpha_2} {c_m}^{\alpha_3} {c_l}^{\alpha_4 - 1} - \lambda_1 w \; + \; \lambda_2 = 0 \tag{16}$$

Rice Production:

$$\frac{\partial \mathcal{L}}{\partial l_r} = \; \lambda_1 p_r \frac{\mu \, \beta_1 \, y_r l_r^{\eta - 1}}{(\beta_1 l_r^{\eta} \; + \beta_2 x_r^{\eta} \; + \; \beta_3 h_r^{\eta})} - \lambda_1 w \; + \; \lambda_2 = 0 \tag{17}$$

$$\frac{\partial \mathcal{L}}{\partial x_r} = \; \lambda_1 p_r \frac{\mu \, \beta_2 \, y_r x_r^{\eta - 1}}{(\beta_1 l_r^{\eta} \; + \beta_2 x_r^{\eta} \; + \; \beta_3 h_r^{\eta})} - \lambda_1 p_x = 0 \tag{18}$$

$$\frac{\partial \mathcal{L}}{\partial h_r} = \lambda_1 p_r \frac{\mu\, \beta_3\, y_r h_r^{\eta-1}}{(\beta_1 l_r^{\eta} + \beta_2 x_r^{\eta} + \beta_3 h_r^{\eta})} - \lambda_1 p_h = 0 \tag{19}$$

Non-rice agricultural productions:

$$\frac{\partial \mathcal{L}}{\partial l_a} = \lambda_1 p_a \frac{\mu\, \gamma_1\, y_a l_a^{\eta-1}}{(\gamma_1 l_a^{\eta} + \gamma_2 x_a^{\eta} + \gamma_3 h_a^{\eta})} - \lambda_1 w = 0 \tag{20}$$

$$\frac{\partial \mathcal{L}}{\partial x_a} = \lambda_1 p_a \frac{\mu\, \gamma_2\, y_a x_a^{\eta-1}}{(\gamma_1 l_a^{\eta} + \gamma_2 x_a^{\eta} + \gamma_3 h_a^{\eta})} - \lambda_1 p_x = 0 \tag{21}$$

$$\frac{\partial \mathcal{L}}{\partial h_a} = \lambda_1 p_a \frac{\mu\, \gamma_3\, y_a h_a^{\eta-1}}{(\gamma_1 l_a^{\eta} + \gamma_2 x_a^{\eta} + \gamma_3 h_a^{\eta})} - \lambda_1 p_h = 0 \tag{22}$$

Constraints:

$$\begin{aligned}\frac{\partial \mathcal{L}}{\partial \lambda_1} = {} & p_r y_r + p_a y_a - P_x(x_r + x_a) - p_h(h_r + h_a) + w\left(\bar{l} - c_l - l_r - l_a\right) \\ & - (p_r c_r + p_a c_a + p_m c_m) = 0\end{aligned} \tag{23}$$

$$\frac{\partial \mathcal{L}}{\partial \lambda_2} = L - \left(\bar{l} - c_l - l_r - l_a\right) = 0 \tag{24}$$

The first four equations (13) – (16) represents optimal consumption decisions for rice, non-rice agricultural products, manufacturing good, and leisure. Equations (17) – (19) gives optimal input use (labor, variable inputs, and land) for rice production. Equations (20) – (22) derive optimal input use (labor, variable inputs, and land) for non-rice production. And equation (23) represents budget constraint whereas equation (24) denotes labor constraint.

The above first-order equations (12) – (24) and market clearing conditions (8) – (10) represents a system of 15 equations which can be solved for the 15 endogenous variables $(c_r, c_a, c_m, c_l, l_r, x_r, h_r, l_a, x_a, h_a, \lambda_1, \lambda_2, p_r, p_a, p_h)$.Given the highly nonlinear nature of the above system, an analytical solution does not exist. Therefore, this system is solved numerically to analyze the impacts of a decline in productivity and land as a results of climate change.

3.4 Data and Calibration

The above system of 15 equations contains 22 parameters (see Table 3), the values of which come from data, literature, and calibration elaborated in this section. This study is based on the Household Income and Expenditure Survey (HIES, 2010) in Bangladesh. In this survey, a total of 4,119 rice farm households were selected for analysis out of the entire 12,240 sample households. Therefore, household demographic information, crop production, consumption of food and non-food items, input used, wage employment were extracted from HIES, 2010 in Bangladesh in order to calibrate the model.

The parameters in the model are calibrated to the Bangladesh rice market based on HIES, 2010. To calibrate the model, different types of information for the total 4,119 rice households are derived from the HIES 2010 survey. From the survey questionnaire and dataset, section 7 of the survey represents information about crop production, consumption, and sales of agricultural products (three types of rice, cereals, vegetables and fruits) for the sample of rice farmers. This section also contains expenses on agricultural inputs used in the production of rice and non-rice agricultural products. Section 9 of the survey contains information about consumption of all food and non-food items. All produced and consumed food items have been converted into kilocalories (kcal) in order to make the unit of food energy unique and comparable. From section 4, farm and off farm activities and wage employment information in the survey questionnaire have been extracted. From section 2, the total number of family members working on the farm and non-farm activities are collected.

Table 3: Exogenous Variables/ Parameter in the Model from HIES, 2010

Parameters	Description	Value
α_1	Share parameter for consumption of rice	0.09
α_2	Share parameter for consumption of non-rice	0.03
α_3	Share parameter for consumption of manufacturing goods	0.86
α_4	Share parameter for consumption of leisure	0.02
d	Minimum (subsistence) amount of rice consumption	2.12
β_1	Share parameter for labor used in rice production	0.01
β_2	Share parameter for other inputs used in rice cultivation	0.22
β_3	Share parameter for land used in rice production	0.13
γ_1	Share parameter for labor used in non-rice production	0.01
γ_2	Share parameter for other inputs used in non-rice cultivation	0.22
γ_3	Share parameter for land available in non-rice production	0.13
μ_r	Returns to scale parameter of rice	0.64
μ_a	Returns to scale parameter of non-rice	0.64
η	Elasticity of substitution	-1
δ_D	Scale parameter for domestic rice demand function	8.43
δ_G	Scale parameter for government rice demand function	8.81
δ_I	Scale parameter for ROW rice supply function	0.38
ϵ_D	Elasticity of demand for domestic rice demand function	- 0.39
ϵ_G	Elasticity of demand for government rice demand function	-0.2
ϵ_I	Elasticity of supply for ROW rice supply function	0.25
σ_a	Scale parameter for domestic non-rice demand function	2.01
ρ_a	Elasticity of demand for domestic non-rice demand function	-0.39
z_r	Rice production scale (productivity) parameter	10.46
z_a	Non-rice production scale (productivity) parameter	1.37

The parameters in the model are calibrated to match the data. This study first calibrates the consumption and production share parameters for different agricultural (rice, wheat, maize, pulses, oilseeds, vegetables and fruits) and non-food items; and then calibrates the demand and supply function parameters for rice and non-rice agricultural goods. $\alpha_i's$ are the consumption share parameters of different food and manufacturing items calibrated by dividing the expenditures of i^{th} consumption goods by total expenditures based on HIES, 2010 data. d is the subsistence consumption parameter that is calculated based on the average number of calories per persons per day (2318.3 kcal/day) and minimal number of calories for a person to survive (1100 kcal/day) from HIES Report.

$\beta_i's$are the rice production share parameters for labor (l_r), other inputs(x_r; seed and fertilizers) and land used (h_r) that are calibrated by dividing each input expenditures to the total expenditures of producing Aus, Aman, and Boro rice together. Similarly, $\gamma_i's$are the non-rice production share parameters for labor (l_a), other inputs (x_a; seed and fertilizers) and land used (h_a) and are calibrated by dividing each input expenditures to the total expenditures of producing non-rice (wheat, maize, pulses, oilseeds, vegetables i.e. potato, onion, garlic, ginger, turmeric, tomato, eggplant, green banana/green papaya, cauliflower, cabbage, pumpkin, radish, green chili, bean, okra, spinach and fruits i.e. mango, jackfruit, banana, papaya, pineapple, melon, guava, etc.) μ_r and μ_a are returns to scale parameters for rice and non-rice respectively calculated from the subtraction of one from $\beta_i's$ and subtraction of one from $\gamma_i's$. Additionally, η is the elasticity of substitution which is assumed to be -1.The rice productivity parameter z_r is calibrated from the rice production function (equation 3) to match the total amount of output (total yield) produced in a year. The non-rice productivity parameter z_a is calibrated from the non- rice production function (equation 4) to match the total amount of output (total yield) produced in a year.

Next, the parameters for the supply and demand function are discussed. $\epsilon_i's$ are the elasticities for demand and supply functions of rice which are obtained from the IFPRI database. The elasticity of demand for rice for the people that do not farm rice is inelastic (-0.39) meaning price of rice increases due to drops in domestic rice supply, rice farmers total revenue also decreases. However, we assume the elasticity of demand for the government is inelastic (-0.2) because the government mainly purchases rice to help feed the poor and are less concerned with price. $\delta_i's$ are the scale parameter for demand and supply function of rice calibrated to match aggregate data using HIES, 2010 data and IFPRI database in market cleaning equation for rice. σ_a is the scale parameter and ρ_a is the elasticity for domestic demand function of non-rice are calibrated to match aggregate data from IFPRI database.

3.5 Simulation and Results

The model is simulated numerically to endogenously determine prices, production, consumption, and welfare. This simulation analysis consists of the baseline and the alternate scenarios. The initial baseline simulation is replicated using the values reported in Table 4. Then the model is run in several alternate scenarios: 1) decreases in land suitable for rice production, 2) declines in productivity, and 3) reductions in both land and productivity due to climate change. By 2050, scientists estimate that the sea-level rise in the delta region could directly affect more than 3 million people. Bangladesh could lose nearly one-quarter (25%) of the land area it had in 1989 by the end of 21st century (Ericson et al., 2006). Alternatively, with the rise of sea-level of just 1 meter, Bangladesh could lose up to 15% of its land area under the sea water as a result of climate change (Denissen, 2012). Furthermore, rice production is always vulnerable to extreme weather conditions and for which rice production may fall by 10% by 2050 (IPCC, 2007). Specifically, for the alternate scenarios, we consider 7.5% and 15%reduction in rice productivity (z_r) and 8.3%, 16.6%, and 25% loss of arable land (H). These declining number of percentages are selected arbitrarily but also considered different literatures estimate given in their results. This study then compares the results of each of the alternate scenarios to the baseline scenario to quantify the potential impacts of climate change.

Table 4: Input Variables/Parameters and Baseline Information

Variables Name	Variables Description	Value
c_r	Consumption of rice	2.24
c_a	Consumption of non-rice	0.01
c_m	Consumption of manufacturing goods	0.22
c_l	Consumption of leisure	25.88
l_r	Labor used in rice production	11.71
x_r	Other inputs used for rice cultivation	0.64
h_r	Land used in rice production	11.89
l_a	Labor used in non-rice production	0.90
x_a	Other inputs used for non-rice cultivation	0.36
h_a	Land available for non-rice production	6.71
λ_1	Constraint 1	0.08
λ_2	Constraint 2	0.01
p_r	Price of rice	1.94
p_a	Price of non-rice	6.85
p_h	Price of land	0.04

Tables 5 - 13 reports the results for changes in the key variables such as consumption, production, price and imports of rice and the non-rice agricultural crop due to declines in productivity and land as a consequence of climate change.

3.5.1 Simulation Results for Rice Market

We analyze the impact of a decline in rice productivity and land reduction on rice production, consumption, price, land use, and imports. These results of are reported in Tables 5 – 9.

3.5.1.1 Rice Production

The farmers' rice productivity declines as climate change reduces the predictability of weather and rising sea level leads to salinization of the soil, which causes a fall in rice production. Specifically, as z_r declines by 7.5% and 15%, holding land unchanged, rice production y_r falls by 5.96% and 11.77%, respectively (first column in Table 5).When there is only rice productivity decline, as shown in Table 8, the rice farmer increases land used in rice production to try to mitigate the effects of the decline in productivity.[3]

Given the low lying regions of much of Bangladesh's rice production regions, as climate change occurs and sea levels rise, land available for farming will become flooded by the ocean and become impossible to cultivate. This will cause a decline in rice production. Specifically, as H declines by 8.3%, 16.6%, and 25%, holding rice productivity unchanged, rice production y_r falls by 0.29%, 0.64%, and 1.06 %, respectively (first row in Table 5). As less total land is available, rice farmer reduce land used in rice production.[4]

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[3] The variable inputs (land and intermediate inputs) also increase to offset the effect of the rice productivity decline, are reported in the Appendix.

[4] As total land available declines and land used in rice production declines, the other inputs in production also fall, are reported in the Appendix.

Even though the decline in land is more pronounced than that of rice productivity, the impact on production is less severe for the decline in land than the decline in productivity. This occurs because a decline in rice productivity results in all inputs to production to be less productive, whereas land loss only reduces the availability of that input in production. The combined effects of a reduction in rice productivity and land are also reported in Table 5. The worst case scenario where productivity declines by 15% and total land falls by 25%, total rice production falls by 12.67%.

3.5.1.2 Rice Consumption, Imports, and Price

The decline in the production of rice leads to a decline in rice consumption. As z_r declines by 7.5% and 15%, holding land unchanged, rice consumption of the farmers c_r falls by 1.10% and 2.18%, respectively (first column in Table 6). As H declines by 8.3%, 16.6%, and 25%, holding rice productivity unchanged, rice consumption of the farmers c_r falls by 0.03%, 0.07%, and 0.11%, respectively (first row in Table 6). Rice consumption does not fall as much as production because imports increase as the price of rice increases. As z_r declines by 7.5% and 15%, imports increase by 2.2% and 4.77% as price increases by 9.22% and 20.39% (from Table 9 and Table 7). Note that the directional change in the price of rice is not known beforehand because it depends on if the decline in production dominates the fall in consumption or vice versa. As indicated above, the net price effect for a fall in both productivity and land is positive and the price of rice rises.

The combined impact of a fall in both rice productivity and land are also reported. For the worst case scenario where productivity declines by 15% and total land falls by 25%, total rice consumption declines by 2.28% and imports and the price of rice rise by 5.2% and 22.38%, respectively. As climate change reduces rice productivity and land availability for rice production, Bangladesh will become more reliant on imports from the ROW but will likely lead to greater price instability, which will make the goal of food security via self-sufficiency more difficult to achieve.

Table 5: Percent Change in Rice Production

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	-0.29	-0.64	-1.06
	7.5%	-5.96	-6.23	-6.55	-6.93
	15%	-11.77	-12.02	-12.31	-12.67

The percentage decline in arable land and rice productivity will decrease rice production significantly. For this analysis, with a 25% reduction of land reduces the rice production by 1.06%, 6.94% and 12.67% when productivity remains unchanged, or falls by 7.5% and 15% respectively.

Table 6: Percent Change in Rice Consumption

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	-0.03	-0.07	-0.11
	7.5%	-1.10	-1.13	-1.16	-1.20
	15%	-2.18	-2.21	-2.24	-2.28

From Table 6 it can be seen that the due to the percentage change in arable land and yield of rice, consumption of rice will decrease. Consequently, when there is a 25% reduction in land and 15% loss of productivity it will reduce the consumption of rice by 2.28%. However, the other variables (income, price etc.) that can influence consumption are considered to be constant here. Furthermore, reduction of land for rice production and yield of rice has a significant negative effect on consumption of rice.

Table 7: Percent Change in Price of Rice

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	0.42	0.92	1.53
	7.5%	9.22	9.69	10.26	10.95
	15%	20.39	20.93	21.59	22.38

The price of rice will increase by 0.42% to 22.38%, which increases the profit of the net rice farmers. On the other hand, the consumer's will be worse off due to rise in rice price. With a decline in productivity by 15%, price of rice will increase by 20.39%. However, with a 25% reduction in arable land will stimulate the rise in price of rice by only 1.53%. As a result, reduction in yield will have more significant effects in increases of rice price. The combined effect of decline in land and productivity by 25% and 15%, respectively increases rice price by 22.38%.

Table 8: Percent Change in Rice Land

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	-8.37	-16.74	-25.10
	7.5%	0.67	-7.75	-16.17	-24.59
	15%	1.51	-6.98	-15.47	-23.95

From the above table it can be seen that the due to the percentage reduction in arable land and productivity of rice, total land use for rice production will decrease simultaneously. Therefore, with the combined effect of decline in land and productivity by 25% and 15% reduces rice land by 23.95%. However, when there is a 25% reduction in total arable land (or a decline of 4.65 million acres), land used in rice production reduced by 25.10% (or 2.98 million acres) while productivity remain constant. Furthermore, the reduction of land for rice production has a significantly negative effect on total domestic supply of rice.

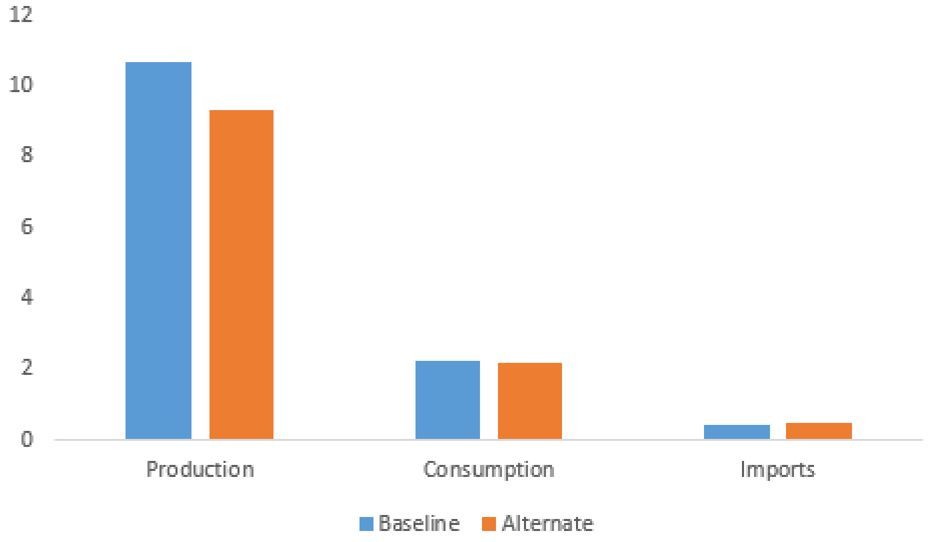
Table 9: Percent Change in Rice Imports

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	0.10	0.23	0.38
	7.5%	2.24	2.35	2.48	2.64
	15%	4.77	4.89	5.03	5.20

From Table 9, reduction of productivity and land by 15% and 25% respectively, results in an increase of rice imports by 5.2%. As the yield of rice decreases, the price of rice will increase for climate change adverse impacts and consequently, the country will import rice in order to fulfill the domestic demand for rice. As a result, a reduction in yield will have adverse effects on the self-sufficiency of domestic food grain production.

In summary, Figure 4 represents graphically production, consumption, and imports for the baseline and alternate scenario for 15% decline in productivity of rice (z_r) and 25% reduction in land (H).

Figure 4: Rice Production, Consumption and Trade Before and After climate change



3.5.2 Simulation Results for the Non-Rice Market

We analyze the impact of a decline in rice productivity and land reduction on non-rice production, consumption, price, and land use. These results of are reported in Tables 10 - 13.

3.5.2.1 Non-Rice Production

The decline in rice productivity implies that non-rice good become relative more productive, which leads to an increase in the production of the non-rice products. Also, when only rice productivity declines, as shown in Table 13, the farmer decreases land used in non-rice production because land is inelastically supplied and the farmer reallocates land to rice production to mitigate the effects of the decline in productivity. However, even though land allocated to non-rice production declines, the other inputs such as labor, fertilizer, and pesticides increase (Appendix Table C1 and Table C2) as the supplies of these inputs are not fixed, which results in higher non-rice production. Specifically, as z_r declines by 7.5% and 15%, holding land unchanged, non-rice production y_a increases by 0.45% and 1.01%, respectively (first column in Table 10). Part of the reason is that the farmer favors rice production by reallocating land away from non-rice to rice production as rice productivity falls as rice fulfils the subsistence requirement d whereas non-rice goods are not used to meet d.

However, as climate change reduce the total land available for farming, non-rice production declines. Specifically, as H declines by 8.3%, 16.6%, and 25% holding rice productivity unchanged, non-rice production y_a falls by 0.22%, 0.49%, and 0.81%, respectively (first row in Table 10). As less total land is available, the farmer reduces land used in both rice and non-rice production as seen in first row of Table 13.[5]

The combined effects of the reduction in productivity and land are also reported in Table 10. The worst case scenario, where productivity declines by 15% and total land falls by 25%, total non-rice production increases by 0.19% (Table 10).

3.5.2.2 Non-Rice Consumption and Price

Even though non-rice production increases because of productivity declines in rice from climate change, consumption of non-rice decreases significantly. As z_r declines by 7.5% and 15%, holding land unchanged, non-rice consumption of the farmers c_a falls by 10.68% and 23.72%, respectively (first column in Table 11). As H declines by 8.3%, 16.6%, and 25%, holding rice productivity unchanged, non-rice consumption of the farmers c_a falls by 0.67%, 1.51.%, and 2.44%, respectively (first row in Table 11).

Non-rice consumption falls more compared to rice consumption even though non-rice production increases because the subsistence parameter $d$is for rice consumption only, and

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[5] Similar to rice production, as total land available declines and land used in non-rice production declines, the other inputs to production also fall.

therefore non-rice goods are only consumed after the farmer meets the subsistence requirement. Note that because non-rice production rises while consumption falls, the decline in rice productivity results in a decrease of the price of non-rice goods. Specifically, as $z_r$declines by 7.5% and 15%, price of non-rice goods decreases by 1.49% and 3.32% (first column in Table 12).However, because both non-rice production and consumption fall as total arable land declines, we do not know whether the price will increase decrease beforehand. However, the price increase as production decreases dominates the price decline as consumption falls and, as total arable land declines by 8.3%, 16.6%, and 25%, price of non-rice increases by 0.56%, 1.23%, and 2.05% (first row in Table 12).

The combined impact of a fall in both rice productivity and land are also reported. For the worst case scenario where productivity declines by 15% and total land falls by 25%, total non-rice consumption declines by 26.24%, and land used in non-rice production falls by 26.86%. This suggest that, if the worst case scenario for both rice productivity and total arable land occurs, non-rice consumption will hit hard because it is not used for subsistence consumption. This raises concern for the balanced diet of the rural population as climate change becomes a reality. According to the HIES (2010) report 31% people lacking minimum of 2,122 kcal/capita/day of food including other basic needs and these people are living below the food consumption based poverty line (HIES, 2010; Basak et al., 2015).

Table 10: Percent Change in Non-Rice Production

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	-0.22	-0.49	-0.81
	7.5%	0.45	0.22	-0.04	-0.37
	15%	1.01	0.79	0.52	0.19

Non-rice agricultural production decreases by 0.22%, 0.48% and 0.81% with the decline in total agricultural land by 8.3%, 16.6% and 25% respectively, remaining rice productivity unchanged. Alternatively, non-rice production increases by 0.45% and 1.01% with 7.5% and 15% reduction in rice productivity considering land constant. However, with a 25% reduction in arable land and 15% decline in rice productivity will stimulate the rise in non-rice production by 0.19%.

Table 11: Percent Change in Non-Rice Consumption

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	-0.67	-1.51	-2.44
	7.5%	-10.68	-11.44	-12.20	-13.20
	15%	-23.72	-24.39	-25.23	-26.24

The alternative scenario reduces the consumption of non-rice agricultural goods which is 26.24% with 25% reduction in land and 15% loss of productivity. Consequently, with a 16.6% decrease in arable land will lower the consumption by 1.51% whereas, with a 15% reduction in productivity declines the consumption of non-rice by 23.71%. So, the decrease in productivity has more significant adverse effect on consumption compared to the decline in land used for non-rice. However, the other variables that can influence the consumption considered to be constant.

Table 12: Percent Change in Price of Non-Rice

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	0.56	1.23	2.05
	7.5%	-1.49	-0.94	-0.28	0.53
	15%	-3.32	-2.77	-2.12	-1.33

The price of non-rice agricultural products will increase by 2.05% with 25% decline in arable land holding productivity constant. Whereas, the price of non-rice agricultural products will decline by 3.32% with 15% decline in productivity if other things remain constant. On the other hand, the consumption of non-rice is going down and that is why the demand for non-rice agricultural goods also drop even though there is increase in non-rice production. But the trend of increase in non-rice production is slower than the flow of decrease in non-rice consumption and consequently the price will also go down. However, with a 25% reduction in arable land and 15% reduction in productivity the price of non-rice agricultural products will go down by 1.33%.

Table 13: Percent Change in Non-Rice Land

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	-8.27	-16.54	-24.82
	7.5%	-1.19	-9.37	-17.55	-25.73
	15%	-2.67	-10.73	-18.80	-26.86

Due to the percentage reduction in arable land and productivity of rice, total land use for non-rice production will decrease simultaneously. Consequently, when there is a 25% reduction in total arable land, land used for non-rice production decline by 24.82% while productivity remain constant. Furthermore, decline in land and productivity by 25% and 15% reduces non-rice land by 26.86%.

3.5.3 Simulation Results for Farm Household Welfare

The results for the impact of decline in rice productivity and a decline in arable land on farmers' welfare are reported in the Table 14.

The farmers' welfare is measured as the consumption equivalent given in equation (11). This welfare measure shows that climate change makes the farmer worse off because they require greater consumption of rice, non-rice, and manufacturing goods are to be equally as well off before rice productivity and land declined. Specifically, as z_r declines by 7.5% and 15%, holding land unchanged, consumption of rice, non-rice, and manufacturing goods falls by 6.28% and 18.09% respectively (first column in Table 14). Precisely, as H declines by

8.3%, 16.6%, and 25% holding rice productivity unchanged, consumption of food and non-food items falls by 0.07%, 0.16%, and 0.26%, respectively (first row in Table 14).

Note that the decline in purchasing power capacity of the rice farmers indicates that directional decline in real income. As climate change reduces rice productivity and land availability for rice production, Bangladeshi rice farmer will become more vulnerable because making it more difficult for the farmers to afford mitigating strategies to cope with climate change and afford basic need of the household.

Table 14: Percent Change in Consumption Equivalent for the Farmers in Bangladesh

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0	0.07	0.16	0.26
	7.5%	6.28	6.42	6.59	6.80
	15%	18.09	18.39	18.76	19.21

The welfare of the rice farmers' will need to increase by 19.21% when there is 15% productivity decline and 25% reduction of arable land to get back to the baseline scenario. From the table, with the highest amount of land reduction by 25% impacts consumption reduction by 0.26% whereas, highest amount of productivity decline by 15% decreases consumption by 18.09%, other things remaining constant and vice versa. Therefore, reduction in rice productivity has significant negative effects on welfare. As a result, reduction in welfare can directly affects the consumption of food for the rice farmers because 54.81% of their income is spent on food (HIES, 2010).

Chapter 4: Conclusion

4.1 Summary and Discussion

In this research we develop an aggregate farm household rice model for the rice producing farmers to analyze the effects of climate change on consumption, productivity, prices of rice and non-rice agricultural products and also household welfare and trade import. The model is calibrated to Household Income and Expenditure Survey 2010 data to quantify the effects of climate change up to 15% and 7.5% reduction in rice productivity and up to 25%, 16% and 8.3% reduction in arable land in the country as a whole.

Climate change has adverse effects in Bangladesh and these hazard reduce the production of rice in Bangladesh while production of other agricultural goods are increasing. Climate change leads to decline in productivity and an increase in price of rice in the domestic markets because the demand for rice is high as a principal food grain. However, climate change lowers the yields and households' welfare, which have negative effects on purchasing power of foods and welfare for the rice farmers as well as the consumer's welfare overall. These differences compared to the baseline of no climate change impacts with reductions of 15% rice productivity and 25% arable land for the entire farms in Bangladesh result in an increase of rice price increases of nominal income for the rice producers and imports, but they result in decreases of their consumption, yields, agricultural lands, and welfare. We consider asymmetric regions information from HIES 2010 because the different districts suffer different types of hazards during different season. Climate change is the major cause to raise in the sea level, increase summer temperature, and increase of flood and cyclone events are almost common in the country.

The results show that reduction in rice productivity decreases rice production by 12.67% in worst case scenario (25% decline in arable land and 15% reduction in rice productivity) while non-rice crop production increases by 0.19% in same scenario. According to the International Food Policy Research Institute (IFPRI) yield of rice possibly will go down between 10% to 15% whereas, rice price will increase between 32% to 37% by 2050 (Nelson et al., 2010). Alternatively, CERES rice model predicted that Boro rice yields would be reduced by over 20% and 50% for the years 2050 and 2070 (Basak et al., 2010). However, the mutual effect of decline in arable land and productivity (25% and 15% respectively) increases rice price by 22.38% and imports by 5.20%.

Alternatively, non-rice production increases by 0.45% and 1.01% considering land constant with 7.5% and 15% reduction in rice productivity. Whereas, the price of non-rice agricultural products will be reduced by 3.31% with 15% decline in productivity if other things remain constant. Consequently, a 25% reduction in land and 15% loss of rice productivity will decrease the rice consumption by 2.28% and non-rice consumption by 26.24%. The change in climate has more negative effects of consumption of non-rice compared to rice because people needs subsistence amount of rice consumption for survive as a staple food which influence the farmer to tie with rice consumption.

Environment professionals have forecasted that, sea level water may rise on average 50 cm to 1.2 meters by the end of 21st century due to increasing temperatures (IPCC, 2013). The World Bank (2000) study found that if the sea level rises up to 1 meter, about 15-17 million people will be displaced from the land inundation reducing by 12-16% of the total land area. Furthermore, in the worst case simulation scenario (decline in arable land by 25%

and rice productivity by 15%) non-rice agricultural land is reduced by 26.86% whereas, rice land decreases by 23.95%.

In conclusion, the decline in arable land decreases the production of both rice and non-rice agricultural goods. The decline in rice production leads to greater imports making food security through self-sufficiency harder to achieve. The decline in rice productivity and arable land reduce farmers' income which leads to a decline in consumption of rice, non-rice agricultural goods, manufacturing goods, and leisure which leads to a decline in rice-farmers' welfare.

4.2 Policy Recommendation

The poor farmer's life with small or marginal landholdings is a high-wire act because they have limited or even any access to improved seeds, irrigation systems, and other advantageous technologies etc. New rice varieties can be developed that may be able to endure extreme heat, extreme cold, high salinization, and water submergence condition. The policy makers and researchers need to accelerate research into new rice varieties and supports smallholder rice farmers through extension and training.

By 2050, global food demand is expected to increase by 60% and climate change would make the situation worse. As climate change reduces rice productivity and land availability for rice production, Bangladesh will become more reliant on imports which will make the goal of food security and balanced nutrition unattainable. It would appear that the fundamental strategy for Bangladesh must be focused on developing the capacity to grow more food and earn more income through access to financing, improved seeds, training, mechanized cultivation technique, and better markets access.

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However, given the importance of a country's food security through agricultural production, maintaining free market policies will be particularly difficult to maintain.

4.3 Research Extension

This model can be extended by accounting for the cost of adaption to climate change, decomposing the farm household according to income levels (high, medium, low), disaggregating farm household into region (high land with drought, coastal with flooding/salinity, hilly areas), and depending on data availability separating production according to growing season (Aus, Aman, Boro), and expand the welfare analysis to include changes in consumer and producer surplus for non-farmer to consider the overall welfare effects of climate change in Bangladesh.

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Appendix

A. Consumption

Table A1: Percent Change in Consumption of Manufacturing Goods

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	-0.13	-0.29	-0.47
	7.5%	-12.06	-12.26	-12.48	-12.76
	15%	-26.25	-26.51	-26.84	-27.23

Table A2: Percent Change in Leisure

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	0.04	0.09	0.14
	7.5%	-3.45	-3.43	-3.41	-3.39
	15%	-8.32	-8.34	-8.37	-8.40

B. Rice Production

Table B1: Percent Change in Labor Used for Rice Production

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	-0.08	-0.18	-0.29
	7.5%	7.56	7.53	7.49	7.44
	15%	18.27	18.32	18.38	18.45

Table B2: Percent Change in Inputs (Fertilizers, Insecticides etc.) Used for Rice Production

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	-0.08	-0.18	-0.29
	7.5%	7.56	7.53	7.49	7.44
	15%	18.27	18.32	18.38	18.45

C. Non-Rice Production

Table C1: Table 12: Percent Change in Labor Used for Non-Rice Production

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	-0.06	-0.13	-0.22
	7.5%	0.76	0.70	0.63	0.56
	15%	1.72	1.67	1.61	1.54

Table C2: Percent Change in Inputs (Fertilizers, Insecticides etc.) Used for Non-Rice Production

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	-0.06	-0.13	-0.22
	7.5%	0.76	0.70	0.63	0.56
	15%	1.72	1.67	1.61	1.54

D. Rental Price of Land

Table D1: Percent Change in Rental Price for Land in Bangladesh

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	0.42	0.92	1.53
	7.5%	9.22	9.69	10.26	10.95
	15%	20.39	20.93	21.59	22.38

E. Real Income of the Farm Households

Table E1: Percent Change in Real Income of the Farm Households in Bangladesh

		Percentage Decline in Land (H)			
		0%	8.3%	16.6%	25%
Percentage Decline in Productivity (z_r)	0%	0.00	-0.18	-0.40	-0.66
	7.5%	-12.55	-12.79	-13.07	-13.42
	15%	-27.07	-27.37	-27.74	-28.18