The Outlook of Supply and Demand of Rice in Bangladesh:

Impact Assessment of Climate Change and Adaptation Policies

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The Outlook of Supply and Demand of Rice in Bangladesh:
Impact Assessment of Climate Change and Adaptation Policies

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Md Abdus SALAM

DEDICATION

My father left many fingerprints of grace on my life. My mother always prays to keep me blessing. In the memory of my parents, this dissertation is dedicated to them for their loves and rules, kindnesses and devotions, and for her endless supports to materialize the nourish dreams.

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ABSTRACT

This dissertation mainly dealt with the impact assessment of climate change on the supply and demand of rice in Bangladesh and generated mid–term outlook of food situations in the era of climate change. Based on simulated results attributed to climate change, an effort was dedicated to developing counter measure options too. In order to achieve those objectives, the study developed supply and demand model to simulate with scenarios of 5th Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) and in addition, also attempted to explore appropriate adaptation policies. The analysis with implemented model had validated that fluctuation of modern and local varieties yields during *Aman* and *Boro* seasons was found higher in RCP6.0 compared to RCP8.5. The variation of consumption and price was further found to be higher in RCP6.0 and SSP2 as well as RCP8.5 and SSP3, but price and consumption would be relatively stable in RCP8.5 and SSP3, nevertheless. The stochastic analysis confirmed that variation of production would expand to the fullest extent compared to that in the historical period. Therefore, yield and rice production would be very sensitive to the stochastic effect of climate variables. Both farm price and retail price would constantly spread and continue to increase in the simulated period. Therefore, persistent increasing spreads of price variation would put the rice security in Bangladesh into daunting challenges.

In order to reduce the effect of climate shock, policy model was incorporated into supply and demand mechanism to investigate counter adaptations that could minimize price variation of rice in Bangladesh. Future projections showed that support price policy through procurement activities could mitigate severe price falls, in favour of farmers. However, price hikes would not be significantly affected. The consequent reduction in price variation (CV) would be 1.49% point and its additional policy budget would be US$151 million. Similarly, subsidized price policy through rice distribution activities could mitigate severe price hikes, in favour of consumers, it, however, would not significantly affect price falls. The consequent reduction in variation (CV) would be 1.38 and necessary policy budget would also be US$79 million. Once, a dual price policy was integrated into the supply and demand model to simulate the result. The simulation could produce on average 2.34% reduction of price variation and resulting reduction of 1% price variation would require US$78 million every year as additional policy budget in the era of 2010–2030.

For important information, the governments of Bangladesh should allocate a good research budget to concentrate on the development of temperature-resilient *Aman* cultivars and develop irrigation facilities where well-developed irrigation facilities are not yet available in *Boro* season. At the same time, a price–stability measure based on future production is required for price stability in favour of both producers and poor consumers in order to meet future challenges of the food security.

This study further evaluated the welfare effect of the climate adaptation policy for public food operation. To mitigate the price variation by 2.34% point would require additional storage of 1.30 million ton. This additional storage would require budget allocation of US$391.7 million for warehouse construction and quality maintenance, which was 0.99 percent of 2016-17 national fiscal budgets. The positive change in surplus that producers would receive was equivalent to US$ 1,981 million in support price policy. Moreover, the change in surplus that consumers would receive was US$ 1,501 million in the intervened years. The counter groups would not be benefited from the individual price policy. On the contrary, the dual price policy could be better and could generate a change in total surplus to US$ 5,532 million. The surplus under dual price policy was found to be higher compared to that being possible through each policy implementation, separately. To adapt the unavoidable climate change and eliminate the number of victims of food insecurity, the impact of climate change on poverty justifies that public food policy must be necessary even if the result of food policy is costly and ineffective. These climate adaptation policies are recognized to be more useful benefiting the producers and consumers during drastic fall in price and tremendous price hikes in the food market in the era of climate change.

Keywords: Climate Change, Supply, and Demand, Price variation, Support price, subsidized price, Food budget and Welfare.

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ACRONYMS

AGD	Approved Grain Dealers
AIDS	Almost Ideal Demand Systems
AR5	Fifth ASSESSMENT Group
BRRI	Bangladesh Rice Research Institute
BINA	Bangladesh Institute of Nuclear Agriculture
BBS	Bangladesh Bureau of Statistics
BIDS	Bangladesh Institute of Development Studies
CMIP5	Coupled Model Inter–comparison Project Phase 5
CV	Coefficient Variation
CMIP5	Coupled Model Inter–comparison Project Phase 5
CERES	Crop Environment Resource Synthesis
DSSAT	Decision Support System for Agricultural Technologies
DW	Durbin Watson
FAO	Food and Agriculture Organization
FPMU	Food Planning and Monitoring Unit
GDP	Gross Domestic Product
GDPD	Gross Domestic Product Deflator
GHG	Greenhouse Gas
GIM	Global Impact Model
GNP	Gross National Product
HIES	Household Income and Expenditure Survey
GR	Green Revolution
HYV	High Yielding Varieties
GCM	general Circulation Model
IPCC	Intergovernmental Panel on Climate Change
IFPRI	International Food and Policy Research Institute
IRRI	International Rice Research Institute
IIASA	International Institute for Applied Systems Analysis
JAMSTEC	Japan Agency For Marine–Earth Science And Technology
MDGs	Millennium Development Goals
MIROC	Model for Interdisciplinary Research on Climate

MOF	Ministry of Food
NIES	National Institute for Environmental Studies
NGO	Nongovernment Organization
OLS	Ordinary Least Square
OECD	Organization for Economic Cooperation and Development
RCPs	Representative Concentration Pathways
RPR	Retail price of rice
SAS	Statistical Analysis System
SDGs	Sustainable Development Goals
SSPs	Shared Socioeconomic Pathways
SUR	Seemingly Uncorrelated Regression
TPC	Temporary Purchase Centers
USDA	United States Department of Agriculture
UNDP	United Nations Development Program
UNFCCC	United Nations Framework Convention Climate Change
US$	Dollar of United States
USA	United States of America
WB	World Bank
WMO	World Meteorological Organization
WRS	World Rice Statistics
2SLS	Two Stage Least Square

LIST OF THE EQUATIONS

INTRODUCTION

1. Background

Bangladesh locates in South Asia from 20°34″ to 26°38″ North latitude and from 88°01″ to 92°41″ East longitude where the tropical weather is the most dominant (National Encyclopedia of Bangladesh, 2017). Moreover, the weather in Bangladesh varies to the fullest extent such as a wide variation in monsoon precipitation, humidity and higher temperatures (Weather Online). Bangladesh is increasingly exposed to a daunting challenge of climate because of low-lying topography, a higher level of poverty, an ever-increasing reliance on climate vulnerable–sector, in particular agriculture and fisheries, and weak institutional arrangements.

More recent days, concepts of climate change and global warming is repeatedly highlighted on changes in weather patterns, extreme temperature and eccentric rainfall that continue to instigate flooding as well as drought. According to meteorological observations, the occurrence of higher temperature is also visualized to persistently increase. More specifically, the country is often predicted to eventually increase a mean day temperatures of as much as 1.0 ^{0}C by 2030 and of 1.4 ^{0}C by 2050 (IPCC, 2007a and b). Besides, rainfall is another difficult challenge that is being experienced to be erratically and highly irregular distribution. The period of rain is becoming shorter, even though the average annual rainfall may be mostly same (Alauddin and Hossain, 2001; UNDP, 2009).

With the occurrence of daunting challenges of climate, an uninterrupted agricultural production and assurance of stable price are threatened and the unavoidable matter appears to sustain the global food security to feed millions of hunger. Therefore, all these that together become great challenges to the agriculture sector, also persists the frightening threats on the existence of human beings.

In essence, Bangladesh continues to be scared of the results of climate change. Alongside, water resources in Bangladesh are mostly dominated by downstream flows of large international rivers which also affect agricultural productivity in the country. Moreover, various devastating and irregular climate continue to put a huge pressure on the economy in Bangladesh, especially through reduction of water resources and causes of crop damages (Huq and Ayers, 2008). Even though the deltaic land and humid tropical weather coupled with plenty monsoon rain water offers a unique habitat for agricultural practices in

Bangladesh, climate change has, however, an enormous impact on crop yield (Sarker *et al*., 2012; Siddika, 2013). Therefore, climate change that could be figured out to alter rice ecosystem, brings a challenging task in the front, especially to carry out constant supply of food for hunger in the country.

Bangladesh is a densely populated country where about 160 million people are dwelling in the area of nearly 147,570 square kilometers (Bangladesh Population Census, 2011; Banglapedia, 2017). Bangladesh has a fairy long history related to cultural and social affairs married to rice cultivation and consumptions. Food consumption is historically dominated by rice which is illustrated too as the only source of nutritional intake for people in Bangladesh. Among various cereals, the primary position is occupied by rice that even dominates the coverage (80%) of cultivable land (BBS, 2014). Henceforth, rice is the dominant crop sub-sector of agriculture which is, in turn, a larger contributor to farm income and also an important source of non-farm income related to transportation and petty business of paddy (Ahmed, 2001). Over the last several decades, Bangladesh had achieved a milestone in rice production in steady manners and could further be enabled to increase yield at satisfactory level (FPMU, 2009; Kumar, 2012). LaFranchi (2015) also updated that Bangladesh had been emerged as a global model struggling against hunger and reached being a county of rice surplus to be freed from the hardship of chronic food shortage. More recently, Bangladesh could had been able to produce enough to make a surplus foodgrain by 2 million tons in the fiscal year of 2014–15 (Kabir *et al*., 2015).

A great challenge is transmitted to continue the stable supply of rice and to forward sustainable food security in the forthcoming (Kabir *et al*., 2015). There is saying that rice security is synonymous to food security in rice growing countries like Bangladesh (Brolley, 2015). Conversely, the growth of population is in an upward trend and is adding nearly 2 million of new mouths to the total population a year. If this trend continues, eventually population increases to 238 million by 2050. At the same time, the cultivable land is constant and regularly loses by 1% due to industrialization and new constructions so on (Kabir *et al*., 2015). With an expanding population and decreasing land-man ratio, climate change poses a new unavoidable challenge to feed the upcoming generation. In hindsight, rice is, therefore, a strategic commodity and political stability of the country, which depends on an adequate, affordable, and smooth supply of rice (FAO, 2014; Nath, 2015). In consequence, each food crisis seemed to stimulate a government and donor activities, and aim at the increasingly stable supply of food and providing better access to food for poor households.

In statistics, Bangladesh is widely recognized as an overpopulated and low-income (US$958 per capita) country where nearly 31.5% of its people live below the poverty line and are vulnerable to food price hikes (World Bank (b)). The almost universal response is a shift in policy sentiment toward greater intervention by governments in order to ensure stable supply of food and control variation of food prices, (Goletti, 1994; Hasan, 2013). Therefore, vulnerability to climate shock, instability of production, and price variation are major features of the food insecurity (Talukder, 2005; Dorosh and Shahabuddin, 2002). For unavoidable present challenges in food sectors, this study is profoundly concerned with the climate change; assess its impact on rice productivity; and analysis the outlook of the food market in the era of climate change and attempts to devise a counter measure for reduction of climate effect on market price.

2. Research Questions

i. How does the climate change hamper supply of rice in the coming decades?

ii. Is the fluctuation of market clearing price being fueled through the impact of climate change on rice production in upcoming period?

iii. Does intervention of adaptation food policy enable to mitigate the price variation perceptibly in the era of climate change?

iv. "How large welfare could the expected allocation of policy budget generate" or "What welfare could the expected allocation of policy budget generate"?

3. Specific Objective

i. To figure out the impact of climate shock on rice production and price variation in the forthcoming time,

ii. To search alternative food policy as adaptation options to the resulting impact of climate change on the variation of market price

iii. To measure the welfare effect of alternative food policy and document the necessity of budget allocation in the era of climate change.

4. Organization of Dissertation

The thesis was designed to proceed in a flow as follows: it started with the background, objectives, and research questions. The whole thesis was divided into eight chapters. Chapter–I, which was very concerned with a review of existing literatures, was again divided into several sections. First, it reviewed the history and success about rice sufficiency. The second section reported on the impact of climate on the crop productivity. The third section was addressed with supply and demand modeling of rice sector and the fourth section did cover food policy activities followed by existing works on adaptation to climate change. This chapter was continued with the discussion of food policy in Bangladesh and ended with a short remark. Chapter–II focused on the concept and theoretical model of the dissertation. A theoretical model was further partitioned into two sections. In the first part, it had been worked with the derivation of supply and demand model. The second part explained the concept of policy model and the building of the functional form of the policies model. Chapter–III was discussed with the methodology. Based on the framework of methods and analyses, the dissertation proceeded to results and interpretations. Chapter-IV was illustrated and elucidated with the impact of climate change on rice production, market price and demand. Chapter–V was dedicated to make an analysis of the stochastic behavior of climatic variable on productivity and market price. Chapter–VI was argued to devise the counter measures for reduction of variation of market price as policy options. Chapter–VII was designated to check the performance of government adaptation policies and welfare effect of those policies in the favour of the society. Last chapter–VIII highlighted comprehensive summary on the conclusions and recommendations. Finally, the thesis ended up with appendix and list of references.

CHAPTER–I
REVIEW OF LITERATURES

In theoretical and also empirical analysis, supply and demand model had been widely used in a regime of economic and policy researches. As this proposed research was overwhelmingly focused the impact of climate change on supply and demand of rice and the relevant counter measures for climate–induced consequences, an in-depth review regarding the related existing literatures were given a more emphasis. To develop more relevant concepts about any proposed research, a review of the literature was an essential job that criticized studies which had already been carried out and that provided a wide range of ideas regarding existing researches and methodical details. In particular, a review helped prioritize the areas of what ought to be undertaken. This chapter reviewed several contents of existing studies such as:i. rice production and its success in Bangladesh, ii. rice and cultivation technologies, iii. overview of rice area, yield and production over the decades, iv. climate change impact on crop productivity, v. supply and demand model of foodgrain in Bangladesh, vi. adaptive expectation and supply responsiveness, vii. climate adaptation policies in Bangladesh and viii. lastly food policy in Bangladesh. Studies, which were reviewed in details, were given in a description of consecutive contents as follows.

1.1 Rice Production and its Success in Bangladesh

Agriculture is still the main driver of Bangladesh economy (which contributes to Gross Domestic Product (GDP) by 14.79%) and inextricably associated with economic development. Rice is a dominant crop sub-sector of agriculture (Bangladesh Economic Review, 2017). Rice is itself the largest contributor to farm income and also the major source of non-farm income (Ahmed, 2001). The ecological environment with the adequate water resources as well as subtropical climate gives a unique habitat that supports the diversity of rice farming in Bangladesh. Moreover, many diverse weather conditions have been favored to widely cultivate rice viz. Upland (pre–monsoon *Aus*), Dry season (irrigated *Boro*) and rainfed condition (monsoon season mainly: low land transplanted and stagnant deep water *Aman* (BBS, 2014).

Prior to the green revolution, the nature of agriculture in Bangladesh was almost subsistence with intensive human labor, low yielding varieties, too much dependency on natural water and manual irrigation without chemical fertilizers. Green revolution (GR) could be defined sets of research and development of crop technologies and to rapidly spread new technologies to farmers' field between the 1930s and late 1960s. The GR brought modern crop seeds, irrigation facilities, and chemical fertilizers. To be freed from Pakistan in 1971, the Bangladesh government invested heavily in the agriculture sector to practice technologies of GR and to boost up adequate food production. GR would bring about unbelievable changes in agriculture productivity and mitigate chronic food deficit especially in developing countries (Hossain, 1988). In addition, the GR could also save billions of lives from an incidence of famine that was a crucial debate in global history. The reason might be that GR ensured the plenty of rice which had been coupled with a wide spread of democracy (International Rice Research Institute, 2017). Over last several decades, the growth of agriculture sector had been triggered enormously by the increasing productivity. Thus, a huge change continued to happen in global food production which could creditably be attributed to the GR.

Ever since the GR markedly in the late 1960s, Bangladesh adopted several approaches to enhance rice production and to achieve the large volume of rice. They were the replacement of local varieties by the quality seed of modern cultivars, cultivation technologies, rapid irrigation coverages, and distribution of fertilizers coupled with the improvement of infrastructures facilities (Bangladesh Rice Knowledge Bank, 2017). With wide ranges of aforesaid activities, the country had made a notable progress in the expansion of domestic rice production. Even though Bangladesh had reached to be sufficient in rice production and broken its vicious chain of food insecurity, it still remained a net rice importer (Dorosh, 2009; Kumar *et al.*,2012; Talukder, 2005). With a sufficient production of foodgrain, the country could be able enough to sustain food–price led inflation in recent years. Therefore, import had been regarded as the supplement to shortage and safeguard to the emergency situation.

1.2 Rice and Cultivation Technologies

Rice is also basic cereal in many Asian countries since antique. Botanically rice, an edible cereal crop and self-pollinated plant (Oryza sativa), has been being widely practiced in tropical regions especially in East and South Asia. It belongs to grass family "Gramineae" and is grown to produce seeds that are cooked and used as food. Rice is commonly specified by Oryza Linn. All kind of rice cultivars that belongs to *O. sativa* in Asia are grouped into four sub species and that have a commercial significant viz. i) indica, ii) japonica, iii) brevindica and iv) brevis gustchin. Non–glutinous rice mostly belongs to Indica rice which is commercially grown and consumed in South Asia including Bangladesh (Grist, 1955).

Moreover, rice has been cultivated in three distinctive seasons in Bangladesh namely: *Aus*, *Aman* and *Boro*. Seasonal crop calendar of rice in Bangladesh is shown in Figure 1.1: *Aus* (Up land rain fed) season that starts from March and ends up at late August; *Aman* (wet season) season that starts from May and ends up at late-December as well as *Boro* (dry season-irrigated) season that starts from the mid-November and ends up in late May (Bangladesh Rice Knowledge Bank, 2017).

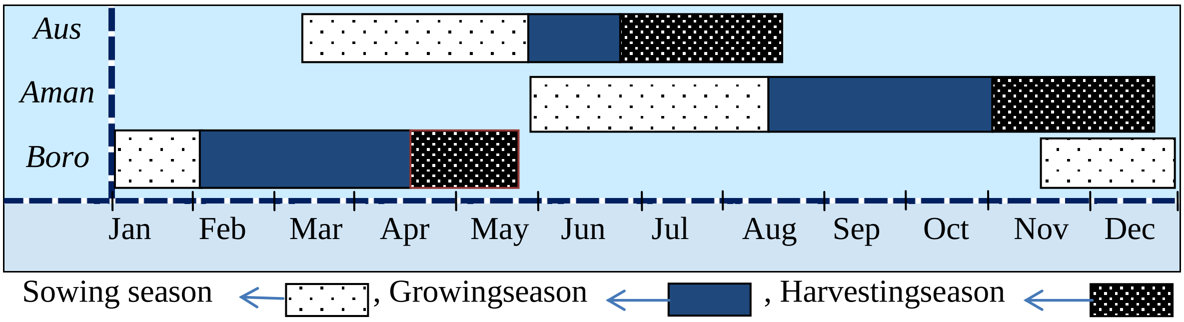

Figure 1.1: Rice growing seasons in Bangladesh (Crop calendar), Source: USDA, 1994

Nevertheless, advancement of science continues to improve morphological and agronomical traits into new genotypes which make a possible to classify rice plants into modern or high yielding and traditional or local cultivars. The modern varieties are those, which are shorter and stronger plant with straight leaf, and higher capacity to absorb nutrient and higher yielder. On the other hand, local variety's plant is longer and weak, flat leaf and comparatively lower capacity to take nutrient and also lower yielder. Each season, farmers practice growing two different types of rice cultivars viz. Modern and Local varieties in their farms (Bangladesh Rice Knowledge Bank, 2017). According to Gene Bank of the Bangladesh Rice Research Institute (BRRI), Bangladesh has conserved a big list of genetic resources of rice (12,000) that have been evolved over thousand years back, collected and listed down as varieties in accession line. All local cultivars as well as modern genotypes have carefully been protected in Germplasm Bank of the Bangladesh Rice Research Institute (BRRI) and the Bangladesh Institute of Nuclear Agriculture (BINA) (Razzaque and Hosain, 2007). All enlisted local varieties are not cultivated in the farmers' field. Up until now, the BRRI continues to release 77 rice genotypes while BINA develops 17 rice genotypes with huge efforts and investments. Genetically, the pure seeds of high yielding cultivars are regularly proliferated and disseminated to farmers' field every year. Farmers adopt to put those improved varieties into practice in order to boost up rice productivity. All these would have been regarded as modern varieties (MV) in Bangladesh which out–yields the local genotypes in different seasons. The rapid adoption of high yielding varieties brought out the remarkable change in the food sector in Bangladesh (Bangladesh Rice Knowledge Bank, 2017).

1.3 Overview of Rice Area, Yield, and Production over the Decades

The high growth in rice production was hard to believe that Bangladesh increasingly experienced, could be attributed to the rapid adoption of modern variety (MV) and expansion of higher irrigation facilities and cheap access to modern inputs. Table 1.1 showed a rapid increase of area coverage under modern cultivars of rice (MV) in the last several decades. In contrast to MV, area under local varieties (LV) continued to get smaller as the day went up. There had been still an ample opportunity to replace areas under LV with the MV rice in both *Aman* and *Aus* (Table 1.1).

Table 1.1Share of area cultivation under modern and local rice cultivars

	Area (%)				
Seasons	1980	1990	2000	2010	2014
Aus					
MV	15.6	17.3	35.2	65.79	76.9
LV	84.4	82.7	64.8	34.21	23.1
Aman					
MV	13.6	29.3	43.2	61.46	72.2
LV	86.4	70.7	56.8	38.54	27.8
Boro					
MV	64.4	88.9	94.6	97.72	98.7
LV	35.7	11.1	5.36	2.28	1.3

Source: BBS, 2014

Table1.2 Growth rates of area, yield, and production (% per year)

Year	Area	Yield	production
1974-80	0.7***	2.2***	2.9***
1981-90	0.2***	2.1***	2.3***
1991-2000	–0.1	1.8***	1.7***
2001-08	0.1***	2.6***	2.7***
1974-2008	0.2***	2.4***	2.6***

Source: Pandey et al. 2012.Using the semi-log trend equation, the annual compound growth rates of area, yield, and production was calculated and *** indicates statistical significance at the 1% level.

Table 1.2 showed that rice production grows more than 2% which could be progressed with an expansion of areas (0.2%) and faster growth in yield (2.4%). Therefore, yield growth was most important gear to continue national rice production in an upward trend. The only effort for dramatic yield growth could be made possible, was because of dissemination and practice of high yielding cultivars.

As stated in the earlier section, there had been three rice–growing season. The explanation could slightly be extended to specify the smart story behind dramatic growth in rice production. In the 1970s traditional/local varieties had been grown in most of cultivated areas (Figure 1.2). With the inception of the GR, MV areas continued to increase most notably since 1970s through 2000s whereas area coverage of LV enormously trend down since then onward (Figure 1.3). Figure 1.2 also pointed out that shifting from local to MVs was very slower in *Aus* season and also showed the somewhat slow trend in local *Aman*. More especially, area coverage had been appeared in Modern *Boro* cultivars to be quite an impressive followed by *Aman* seasons. In addition, higher expansion of *Boro* areas had been possible from areas sacrifice of local *Boro* and overlapping *Aus* areas. Rapid area devotion under MVs, which was induced by the availability of huge modern inputs and facilities, could be referred to by the government endeavors that made larger interventions to enhance food grain production (Hossain *et al*. 2003; Alam and Islam, 2013).Figure 1.4 and 1.5 appeared that yield growth was higher in *Boro* varieties than that in *Aman* and lowest growth in *Aus*, even though more than 50% of rice area was still occupied by *Aman* rice. The result of increasing yield trend in *Boro* varieties was of higher seasonal potentiality coupled with potential cultivars and extensive facilities. On the other hand, *Aman* and *Aus* that were the most dependent on the natural source of water especially rain, given relatively less attention than *Boro* (BBS, 2014).

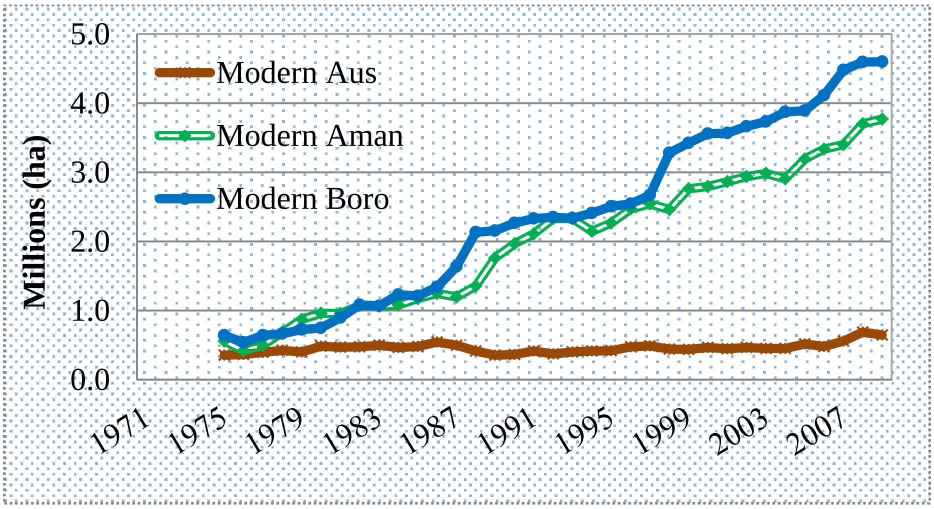

Figure 1.2 Seasonal areas of modern rice genotypes

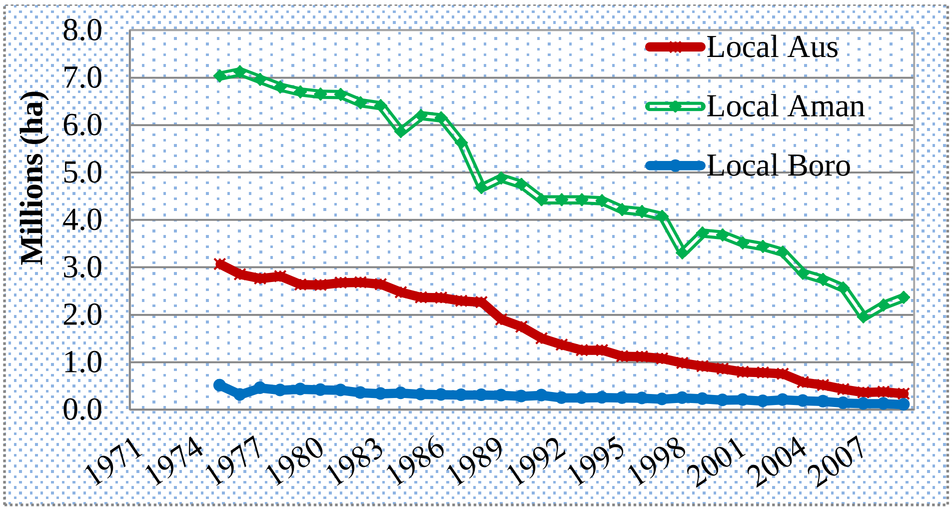

Figure 1.3 Seasonal areas of local rice cultivars

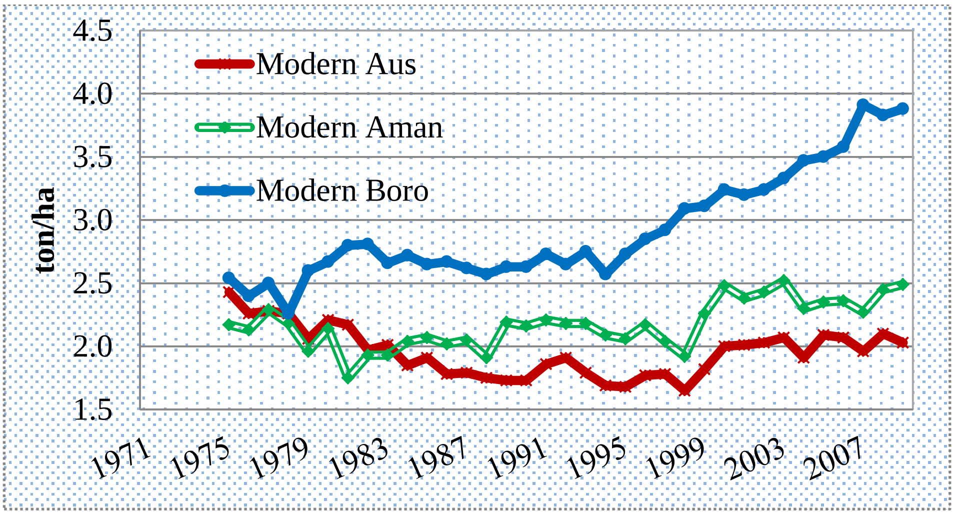

Figure 1.4 Seasonal yields of modern rice genotypes

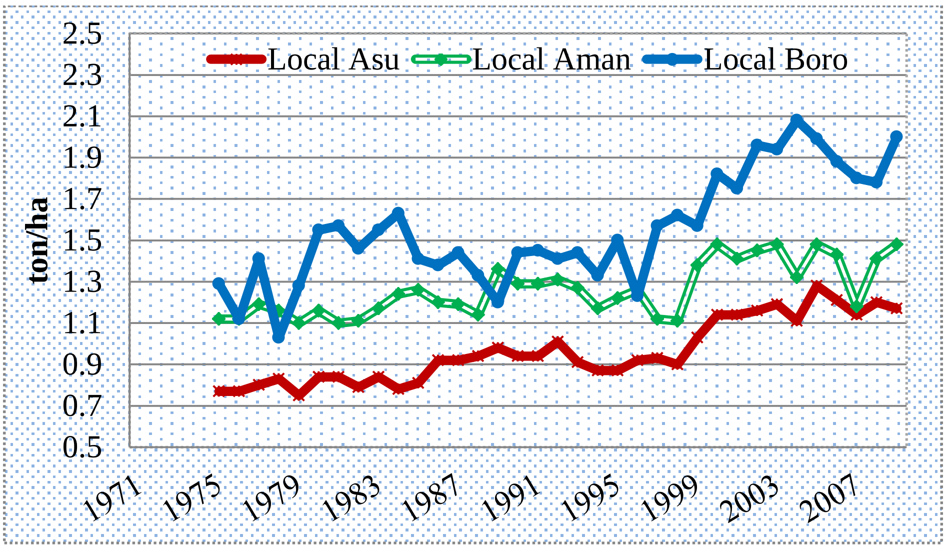

Figure 1.5 Seasonal yields of local rice cultivars

1.4 Climate Change Impact on Crop Productivity

Globally, CO_2 emission and sea level rising, which had been observed faster, caused the changes in weather, excessive rainfall, flooding and drought in different parts of the world. Climate change was presumed to reshape the regional climate including strength and timing of Asian monsoon. Polar Regions had been melting as a consequence of faster warming, that resulted in a rising water levels in the sea. All these phenomena, that could frequently be noticed recently, were an obvious result of human activities, rapid economic growth, and development. Every growing economy persisted to emphasize the rapid expansion of industry and transportation utilizing gasoline and natural gas which, in turn, speeded up Greenhouse Gas (GHG) emission (Trenberth *et al*., 2000; Masui *et al*., 2011).

Global climate change was no more a presumption and it would rather become a reality. Faster concentrations of GHG in the atmosphere area were the major driving force to warm up the global surface and subsequent changes happened in climate parameters (Sattar *et al*., 2012). The rapid growth of economic activities in Asia resulted in GHG emission (mainly CO_2 emission) as projected to exceed 60 percent of global total emission by 2100. High emission increased the temperature, shaped the strength and timing of monsoon, speeded up snow melt and shortened winter (Masui *et al*., 2011). With uncertainties in future GHG concentration and climate sensitivity, the surface temperature would likely be happened to increase from 1.1°C to 6.4 °C by 2100 than in 1980–1999 (IPPC, 2007). More recently, IPCC updated of what had been done as climate model in Fifth Assessment Report (AR5) in 2013, was improved more than that was built in Fourth Assessment Report (AR4) in 2007. IPCC showed new results related to risk management of extreme events and reduction of disasters outcome. The visible result of climate changes had been unprecedentedly observed over the decades. Under the assumptions of four concentration scenarios "Representative Concentration Pathway (RCPs)" global mean surface temperature would be predicted, most likely, to rise by 1.1°C to 4.8 °C at the end of 21st century relative to that in 1986–2005 (Stocker *et al*., 2013).

The prospect of global warming that was thought to be dreadful consequence from rapid GHG emissions that would be a major concern regarding the potential effects on rice production (Wassmann *et al*., 2009). Notably, rice yield was be much responsive to nighttime temperature implying that due to 1°C increase in nighttime temperature, approximately a 10 percent of rice yield would be decreased (Peng *et al*., 2004;Welch *et al*., 2010). Many studies showed identical results that increasing nighttime temperature might be driving wheel of increases in global mean temperatures since mid–20th century, and thus continued to cause yield reduction (Sheehy *et al*., 2005; Shah *et al*., 2011,). An increase in both nighttime and daytime temperature might also increase an number of grain damages (Morita *et al*., 2002). With the reduction of rice yield, the concentration of GHG coupled with high temperature might affect the quality of rice. Ceccarelli *et al*. (2010) also testified that yields of rice were estimated to be reduced by 41% by the end of the 21st century. Conversely, in some areas temperature increase would improve the crop establishment of rice, for example in Mediterranean areas, where cool weather usually caused poor crop establishment (Nakagawa *et al*., 2003). Increased CO_2 was expected to have positive effects on crop yield but the overall results of CO_2 concentration were detrimental or might outweigh cumulative of positive results, particularly in the tropics, where world's poor lived (Mackill *et al*., 2010). Despite technological advancements in agriculture such as improved seed-fertilizer-irrigation system; the weather had been an important factor, which played a vital role in determining the productivity. Agricultural production would be greatly influenced by the increase of global warming through changes in yields and market prices during the 21st century (IPCC, 2007; Master *et al*., 2010).

Therefore, the food system globally would be dominated to a greater degree by the speed of climate alteration. Significant alterations in climatic reduced food availability through crops injury and diffusion of its adverse impacts locally and globally (Molua, 2002 Isika and Devadose 2006 and World Bank, 2013). The scholars were also greatly concerned with coincident of climate change and population growth in developing countries that were challenged to be so terrible. In one hand, climate effects would degenerate agriculture productivity and on other hand, demand would increase from higher growth in population which might validate Malthus's fears, resulting in food shortages (Thomas *et al*, 2013; Anderson *et al.* 1989).

There was, however, certainly no exception for Bangladesh. Increasing the temperature, increased precipitation, thermal expansion of the Bay of Bengal and melting of the glaciers in the Himalayas would have great impacts over Bangladesh. Bangladesh, being enormously reliance on the agriculture, constantly would come across adverse effect of climate alternations due to the high emission of GHG from rapid economic activities in Asia. The diverse climatic phenomena like cyclone, drought, changing rainfall patterns and temperature; would cause a significant losses in food grain production in every year. Low yield could happen with the consequence of heavy rainfall when the crops were washed in a sudden flood. A 2°C rise in minimum temperature would result in the crop yield reduction by

800kg/ha in every season in Bangladesh (Siddika, 2013). It was denoted that rice production was increasingly affected by climate events such flood and drought that frequently happened and that was the consequence of growing temperature which even cause until 100% losses of the crop yield (Mottaleb *et al.*, 2016).In contrast, Faisal and Parveen (2004) studied the negative impact of climate change on rice yield that would probably be lower due to positive fertilization of CO_2 in compensation of higher negative impact of increasing temperature and rise in sea level. By the end of 2050, production of rice would decrease noticeably by 8%. Moreover, increasing population growth and environmental degradation exacerbated climate change effects on agriculture of Bangladesh (Ahsan, *et al*. 2011). Mamun *et al.*, (2015) found that climatic variables (temperature) were responsible to explain 23%, 91%, and 89% of the variance of crop yield in *Aus*, *Aman* and *Boro* seasons in Bangladesh, respectively. Many other studies had also investigated the variation of crop yield and estimated huge loss due to effects of climate change with the application of crop models (Kabir, 2015; Karim *et al.*, 1996). Kobayashi and Furuya (2010) examined long run growth rates of the yield of rice in Bangladesh that would more inevitably be required to advance the food security in the era of climate change. On the other hand, Furuya and Koyama (2005) also conducted a mid-term simulation and examined the relationship between climatic factors and world food markets. Their study also confirmed that the rice yield in South Asia would drastically be reduced due to the higher temperature. To avoid the predicted consequences, their studies advocated a change in cropping pattern and management practices as adaptation measures to protect yield losses. In addition to production practices, Kobayashi and Furuya (2011) proposed a suitable adaptation strategy in order to secure national food system in Bangladesh through the application of longer simulation on climate change. Furthermore, their study denoted that impact of higher temperature would be more serious on yield decrease than sea level rising. To make a closing remark, they recommended doing more research and development strategies to figure out the consequence of climate change and create the more solid ground of policies. In addition, Kobayashi and Furuya (2011) proposed a 3% and 1.5% growth rates which would be necessarily ideal yield for dry and rainy seasons to sustain the food security in the face of climate and population growth. Consequently, the cumulative impact of climate change on rice would be more negative than positive.

Unavoidable heat shock and lack of anticipatory adaptation lead to significant losses in yield and continue to be a terrible threat to rice production (Paul *et al.*, 2016). Major studies of climate variables on agricultural productivity in Bangladesh case, which were expected to support the proposed research, were given in Table 1.2.

Table 1.3 Major studies on climate impact on rice productivity in Bangladesh

Authors and year	Main objectives	Data and method	Important findings
Sarker *et al*., 2012	• examined the relation between climate and paddy yield	• Time series data • Multiple and quartile regression	• Climate variable had an enormous effect on seasonal yields • Temperature had negative effect on yield of irrigated crops
Sikder, 2014	• reviewed the impact of climate change on Agriculture in Bangladesh	• Review paper on the existing works regarding climate and its consequences on life and livelihoods	• The consequence of climate was increasingly growing to be popular in global concern. The climate change was predicted to bring the vulnerability of the lives and livelihoods of Bangladesh into the forefront.
Basak *et al*., 2010	• assessed the climate effect on irrigated rice production (Boro)	• Time series data • Crop modeling (DSSAT)	• Average yield reduction would be 20% and 50% in rice genotype (BR3 and BR14) in the years 2050 and 2070, respectively. • Daily minimum and the maximum temperature had an adequate negative effect on yield reduction in the aforesaid years.
Kabir, 2015	• assessed the climate impact on three crops production in Bangladesh	• Time series data for 12 locations (districts) • Use the CERES rice model and	• More than 20% and 50% yield will be reduced for BR3 and BR14 in irrigated season.

		DSSAT modeling system	• Climate change made crops more vulnerable and delayed transplant, especially beyond 15 January decline the yield potential.
Karim *et al.*, 1996	• assessed the vulnerability and impact of climate change on foodgrain production in Bangladesh	• Applying the CERES–Rice and Wheat model with the time series data	• With the growing CO_2 (350, 580 and 660ppm), the sensitivity analysis of temperature increase until 2 and 4°C had a detrimental effect on rice yield. • A 35% and 31% yield reduction of rice and wheat respectively would be noted.
Amin *et al.*, 2015	• analyzed the nexus between climate change and crop yields	• National level time series data • Linear regression model	• Maximum temperature coupled with uneven rainfall adversely fueled declining rainfed rice yield.
Iffat *et al.*, 2016	• understood the relative influence of spatial– temporal variation of climate, cropping intensity and irrigation means on rice yield	• Spatial time series of national statistics and meteorological statistics were used. • Linear mixed model to identify the determinants of rice yield and Geographic Information Systems (GIS) was used.	• Temperature and rainfall had execrably negative upshot on rice yield. • Groundwater irrigation influenced the determination of yield enormously compared to climate and cropping intensity. Moreover, rice yield continued to decline with the increase of cropping intensity.
Iqbal, 2008	• studied the impact of climate change on agricultural	• Panel data at the national level from 1975–2008.	• The long term change in average and mean deviation had the differential impact on the

	productivity in Bangladesh	• Regression model was applied to estimate the impact of climate change	productivity of rice.
Hussain 2010	• assessed the climate change related vulnerability on food grain production in Bangladesh.	• The study was carried out in six districts for rice and three districts for wheat. CERES–rice and DSSAT model was used	• Notable impact of climate change on food grain production in Bangladesh could appear

1.5 Supply and Demand Model of Foodgrain in Bangladesh

Bangladesh faced the daunting challenges to feed people immediately after the country became Independence in 1971 (Haggblade, 1994). The infamous famine happened in 1974 which claimed 1.5 million lives. Food shortage in the world market and no foreign exchanges had been regarded as the main reason for what unexpectedly happened in Bangladesh in that period. Henry Kissinger, who had been former US National Security Advisor, once stated that as a "Bottomless basket" the food sector of Bangladesh had been illustrated with famine–prone and higher poverty which remains fabulous public debate quite long period (Rahman and Tipu, 2002). Implementing numerous policy dimensions had been undertaken to get free from severe famine outbreak. Over decades, Bangladesh hardened to take the higher benefit of cutting edge technologies and enjoys dramatic advancement in food grain production. In addition, the increased agricultural productivity dictated farm income and fueled the rapid growth in rice production. On the other hand, food grain markets continued to flourish steadily over last few decades and underwent a number of fundamental transformations. Even though supply and demand balances of rice repeatedly evolved in deficit, by the end of current decade, Bangladesh had made an incredible success to achieve the substantial surplus and struggle the utmost to move from severe food deficit to sustainable surplus producer. Total rice production had been more than doubled and increased the transaction of market quantity immensely. Thus, net availability of foodgrain in Bangladesh had been progressively in the upward trend. Moreover, overall livelihoods were headed with the increasing trend in foodgrain production. Rising growth of the production enabled the government to introduce a series of structural change and allowed participation of private trade in the international market (Chowdhury *et al*., 2006).

Talukdar (1990) examined the demand of six food items consumption according to various income classes using national Households Income and Expenditure Survey 1981–82 and Bangladesh Bureau of Statistics. He criticized scrupulously that income difference occurred most prominently among the household income groups that discriminated the impact of income change on consumption in rural and urban areas, respectively. Howbeit, average price change and income change remained invariant across the rural and urban households. Ahmad and Shams (1994) found almost similar results that effect of income change varied according to income group, but low income households were most promptly reacted to price and income change. Zohir *et al*. (2002) remarked that demand for high–quality rice was growing faster with the pace of urbanization and high income growth. They added that major determinants of supply could be attributed by proper utilization of land across various agro–ecology and coverage of irrigation facilities those together affected the famers' choice. More research and rapid extension efforts could also be leading determinants to the productivity of individual crops. Islam (2002) suggested further possible breakthrough in rice yield to boost up supply in order to challenge demand balance in long course of time. Aktarul (2011) also found the real price and irrigation coverage which had enormous influence on an increase in the rice production. He also estimated that, price elasticity of rice was negative 0.81 while price elasticity of wheat was negative 0.48, denoting that both foodgrain remained main dishes in the dining table in Bangladesh.

Murshid *et al*. (2008) projected a reliable surplus of paddy production which, albeit constantly higher growth of population and income that would increase the consumption, could be made possible through higher productivity in paddy. Rising GDP and income growth were taken up to stimulate the increasing demand for protein rich food like meat, fish, and egg other than cereal like paddy.

Conversely, it was predicted that the annual demand for food exceeds the supply of food up to 2021 which were -0.28% for rice denoting the food deficit condition (Begum *et al.* 2010). Kumar *et al*. (2012) predicted the gap between supply and demand for 2015 through 2030. They stated that Bangladesh would encounter both challenges and prospect which could be termed as "deficit or surplus". High population growth would lead to the deficit of 13.7mm tons and surplus could be made possible by 2030 to 4.2 million ton through higher productivity.

Kobayashi and Furuya (2011) modeled the degree of climate impacts to unravel more possible adaptation strategies which would be given most priority to simulate the climate change. In order to achieve the great challenges, impact response functions of climate events were developed and simulated into the supply and demand too. The result of this study indicated that high temperature had an enormous impact to secure enough food in the long course of climate alteration.

Therefore, the questions of sustainable rice production and the overburdened growing population gave overwhelming and desperate challenges over again. Existing research related to supply and demand regarding supply and demand of foodgrain in Bangladesh was reviewed in the Table 1.4.

Table 1.4 Major studies of rice supply and demand model in Bangladesh

Authors and year	Main objectives	Data and method	Important findings
Talukdar, 1990	• estimated parameters of six food items consumption	• Data were utilized from national Households Income and Expenditure Survey 1981–82 and Bangladesh Bureau of Statistics. Data disaggregated by income group is used to investigate the income effect on consumption pattern. • Parameters are calculated using double log–linear demand function.	• The income difference among the household groups mostly made the difference in the value of parameters in rural and urban areas. • The effect of price change and income change remained invariant among the rural and urban households. • The study found the estimation bias was arisen from consumption and home supply.
Ahmad and Shams, 1994	• estimated the demand elasticities for food commodity in rural areas	• The study used the primary household survey data in 1991/92 and estimated parameters of demand function using Almost Ideal Demand System (AIDS).	• The study confirmed that the households were more responsive to change in income quickly to alter their consumption pattern. • Disaggregated income analysis states that lower income group was more responsive to price and income change than higher income group.

			• The study recommends the government price policy intervention to support the lower income group.
Ahmad, 1997	• used the comparative static framework for rice market so as to pursue the issue of causality in the falling rice prices, the demand and supply functions of rice	The comparative static framework in the model in the followings case: $QS_{it} = f(P_{it,}T_t); QD_{it} = f(P_{it,}P_{jt,}Z_{it}, Y_{it})$ $QS_{it} - QD_{it} = 0$ where QS_{it} = supply of rice in year t, t_1 = initial year, t_2 = final year; QD_{it} = demand for rice in year t; P_{it} = price of rice in year t; T_t = state of technology in rice production in year t; P_{jt} = index of prices of consumers' goods other than rice in year t; Z_{it} = demand shift due to change in urbanization;	• The study found that, of a total demand depressing effect of 15.6 percent, urbanization accounts for 4 percentage points, cross-price effects for 7 percentage points, and worsening income distribution accounts, residually, for 4.6 percentage points. • These findings were based on plausible values of demand and supply parameters which warrant in-depth evaluation in the context of rapid structural change in the economy of Bangladesh.

	•	Y_{it} = income level of consumers in year t. Supply and demand response to the change in variables was figured out with the mathematical exposition of differentiation.	•
Zohir *et al*., 2002	• provided detail information on recent development in rice sector and develop the outlook of supply and demand balance of rice in Bangladesh in the 21st century. • gave an overview of food and agriculture policy associated with recent macroeconomics and sector base policy changes denoting the implications of production incentives	• National statistics on time series. • This study was carried out using two independent analysis of rice supply and demand. • The parameters of supply are estimated using the dynamic supply response (McGuirk Mundlak model) of rice and substitute crops enterprises and, in addition, seemingly unrelated regression (SUR) estimation method. • A multistage budgeting demand system is modeled to estimate the parameters of demand functions. • Supply and demand balance of rice was projected using very "common sense" approach under the concept of no trade regime. Determination of market clearing	• The area devotion under *Boro* rice grows faster in response to expansion of private irrigation which happened only at the expense of wheat areas. • The variation of annual domestic price pronounced enormously which calls for government intervention on input subsidy and support price for output. • Demand for high–quality rice was growing faster with urbanization and growing income. The major determinants of supply include land use by agro–ecology and irrigation areas that affected the famers' choice and Research and extension efforts that determined the productivity of individual crops.

		price was ignored. The author argued that this may not affect the result as the price elasticity of supply was not significant. Demand projection separately was conducted using income and population growth.	
Islam, 2002	• estimated the supply and demand situations of rice especially aromatic rice and also to project the future situation.	• Supply and demand are independently estimated using the supply response and linear approximation of almost ideal demand System, respectively. • Multistage households' data are used in demand systems analysis for specific urban and rural areas.	• The supply and demand balance was estimated using alternative scenarios. A 5% increase of rice area was not able to produce aromatic rice that exceeds its demand. A 10% increase of rice area could be produced excess supply over demand. • The decreasing trend of supply and demand indicated the need for the further breakthrough in rice yield. • A 10% increase in price of coarse rice lead to reduce its demand by 7.7%. A 10% increase in income decreased the demand for coarse rice and oppositely increased the demand for aromatic rice.

Murshid *et al.*, 2008	• forecasted the supply of food grain in the year 2020.	• Alternative data source were used to validate production data in the Bangladesh Bureau of Statistics (BBS) and the supply of food was forecasted using simple linear prediction method in the year 2020.	• The supply projection produced a reliable surplus of paddy production even though the consumption with high population growth as well as income would increase constantly.
	• estimated the food requirement in a typical manner in order to derive the nutritional standards in pace with the urban mobilization of the population.	• Demand elasticities for food items were estimated using the linear approximation Almost Ideal Demand System with SUR method and data were adopted from Households Income and expenditure Survey (HIES) in 2005. • Income and population growth were used to predict the food demand in the future.	• Rising GDP and income growth stimulated the increasing demand for protein rich food like meat, fish, and egg.
Begum and Haese, 2010	• examined the food availability and market demand. • Also determined the dynamic balance between the supply and demand at the national level.	• National statistics on the growth rate of the target variables were used • Ohkawa's formula was used in this study which incorporated population growth and modified income growth rate to estimate the growth rate of food demand which would be required in the future.	They found that the own price and income elasticities of rice were negative 0.108 and positive 0.199 respectively. They project that the annual demand for food exceeded the supply of food up to 2021 which were -0.28% for rice and -1.76% for wheat denoting the deficit condition of foods.

		The model was stated below: $\Gamma_D = \Gamma_S = \Gamma_p + \lambda\Gamma_g - \lambda'\Gamma_x$ Where, Γ_D was the growth in demand, Γ_p was growth in population, Γ_g was the growth in per capita income and λ was income elasticity in food demand. Γ_x was variation in prices and λ' was price elasticity of demand. The model could basically be able to analyze demand-supply gap.	
Huq and Arshad, 2010	• assessed the effect of price change and substitution effect among different food items.	• Data were extracted from household expenditure survey, 1983–84, 1988–89, 1991–92, 1995–96, 2000, 2005–06 • This study also applied almost ideal demand system and estimated parameters with SUR method.	• This study could not produce any significant difference in absolute value of expenditure elasticity and own price elasticity over the time period. • Therefore, government policy intervention could not impact the economy significantly. • The study suggests the combination of price and income policies would be more effective way to impact the

			economy.
Akhtarul, 2011	• Investigated consumption pattern and estimate demand elasticity for rice and wheat. • estimated the growth and supply response function which includes price and nonprice factors.	• Time series data from national statistics and FAOSTAT. • Demand elasticity for food grain was computed using LA/AIDS model and SUR method for 1980-2006. • The supply response of rice and wheat were constructed using Nerlovian partial adjustment model associated with co-integration for 1980-2009.	• The expenditure elasticity was 0.91 for rice while 1.48 for wheat. • The own elasticity of rice and wheat was negative 0.81 and negative 0.48 indicating that rice and wheat were necessity goods, respectively. • The Engel and Granger co–integration test confirmed no distinctive long run equilibrium relationship among variables of supply response function. • The real price and irrigation coverage had enormous influence on the rice production.
Kobayashi and Furuya, 2011	• compared the degree of climate impacts so that most possible adaptation strategies would be designated and given priority to stimulate the climate change into supply–demand system.	• Divisional level time series datasets. • This study incorporated impact response functions of the flood, high temperature and seas level too in the supply and demand model of Bangladesh. Impact response of flood	• The result of this study indicated that high temperature had an enormous impact on food security in the long future than other climate impactd like flood and seas level rise.

$ZD = aT^2 + bT + c$ where ZD was scaling factor of the damaged area by the disaster which depended on the rise in average temperature (T).

Impact response of Temperature

$ZY = aT^2 + bT$ where ZY was the percent change rate of crop yield that also depended on the rise in average temperature (T).

Impact response of Sea level Rise

$ZA = aH^2 + bH$ where ZA was the reduction rate of suitable land for crop cultivation that depended on the sea level rise (Hcm).

- This research did not incorporate precipitation, solar radiation and not highlight on policy measure in the era of climate changes.

Kumar *et al.*, 2012	• assessed the gap between supply and demand and predict supply and demand for 2015, 2020 2025 and 2030	• National Statistics: i. Bangladesh Bureau of Statistics ii. Household Income and expenditure Survey, 2005 • Supply of rice in three seasons was modeled through a separate area and yield function for 1981–2002. • Direct and indirect demand was modeled using quadratic almost ideal Demand System (AIDS) for 13 food items in 2005. • Three simulation scenarios: Business as usual scenario (BAU), • Pessimistic scenario (PS) and Optimistic scenario (OS) on: i. the growth of cultivation, irrigated and MV area in the supply side • the growth of per capita Gross National Product (GNP) combined with population growth in the demand side.	• The estimated expenditure elasticity for the demand of rice was 0.85 and own–price elasticity was –0.3623 indicating that rice was a necessary food in the food basket in Bangladesh. • Assuming constant prices, they projected per capita household demand would be the range of 183.7 to 192.3 (kg) for the year 2030 for rice and also projected on other cereal • Bangladesh would face surplus or deficit depending on the supply – demand scenarios and intermediate requirements • Sharp climb in rice demand would be noted under the high population growth • The surplus in 2030 would be nearly 4.2 million ton, whereas the deficit could be as much as 13.7 mm tons.

The study of Kobayashi and Furuya (2011) had been the more remarkable study on supply and demand that compared consumption in alternative climate scenarios and suggested adaptation strategies to secure expected balance between supply and demands in the future. They also suggested further study with possible alternative climate scenarios to make more suitable strategic planning and adaptation policy that could shed more light on food policy measure in the era of climate changes.

However, most of the previous studies regarding the supply functions which were accomplished only by employing supply response approach and regarding demand for consumer commodities which were accomplished by employing almost ideal demand system (AIDS). They did not investigate variation of market equilibrium price and trade conditions under evolving climate pattern in Bangladesh as for an example $(NSR \div POP) - DDR = 0$ where NSR was total supply in the market was, POP was the population and DDR was the per capita consumption. Previous studies also made a substantial effort to show the surplus or deficiency between demand and supply without market clearing mechanism. To consider existing theoretical limitation, the present study was deeply employed to generate more accurate outlook of rice supply and demand under climate change and as such the far better attempts were dedicated to develop more strategic recommendation of rice production, per capita demand, stock change, and import decision etc. Furthermore, the proposed study was given most emphasis to investigate climate effect on variation of market clearing price and supply. In order to highlight the impact of alternative scenarios, this study proposed to assess climatic scenarios of RCPs of Intergovernmental Panel on Climate Change (IPCC) in combination with shared Socioeconomic Pathways (SSPs) of International Institute for Applied System Analysis (IIASA). More specifically, this piece of research broadly emphasized on a supply and demand that could measure the magnitude of climate effects on market clearing mechanism underAR5 of the IPCC.

1.6 Adaptive expectation and supply responsiveness

Empirically, there had been two approaches under wide utilization to work out the agricultural supply response viz. programming and the econometric approach. Both approaches had merits and demerits that should have been brought to mind during the application of estimates. The present work mostly focused on the construction and estimation of supply response model in the light of econometric approach.

Farmers were usually practicing farming in risk environment which cannot easily be measured in a numeric unit. They could compute the profit and losses through the quantification of the cost and return in terms of market price. Many economists assumed that producers anticipated the markets price from their rationalization and formulated their expectations of future price where they also took past prices into account that they confront (Muth, 1961; Nerlove, 1958; Lovell 1986). Rahman and Yunus (1993) investigated the effect of prices policies and policy reforms on the supply response of major crops to explain farmers' expectation behavior using theoretical framework postulated on the basis of Nerlovian adaptive expectation. Many studies introduced adaptive expectation approach in construction of supply response function that explained farmers' expectation behavior to allocate land under agricultural farming practices in Bangladesh. Farmers had an excessive control on the land allocation other than yield which was increasingly attributed to the influence of climate, technological advancement and land quality (Yaseen *et al*. 2011). Dorosh *et al*. (2001b) made a bunch of reviews about the theoretical application of adaptive expectation approach in his paper. He concluded that all studies used expectation approach to the responsiveness of the aggregate acreage data.

Many other studies including Dorosh *et al*. (2001b) investigated the responsive of the disaggregated acreage to the season, variety as well as non–price factors (Krisna, 1962; Gulati and Kelly, 1999; Rahman and Yunus, 1993; Barmon and Chaudhury, 2012; Ahmed and Bernard, 1989). Huq *et al*. (2013) measured the supply response of wheat production as an alternative to adaptive expectation and further explained that vector autoregressive (VAR) model could produce more accurate as well as a non spurious result. He constructed supply response function using Johansen maximum likelihood as well as VAR model such as:

$$Z_t = A_t Z_{t-1} + ... + A_k Z_{t-k} + U \tag{1.1}$$

where $Z_t = (n \times 1)$ was the vector of the $I(1)$ variables (including both exogenous and endogenous variable) $A_t = (n \times 1)$ was a matrix of parameters and $U = (n \times 1)$ was the vector of the white noise.

Mythili (2008) undoubtedly concluded that Nerlovian adjustment cum expectation approach was widely accepted and superior to other alternative model. This was a because that Nerlovian framework could compute the short run and long run responses including the speed of adjustment in order to move from actual to the expected level of land or other resources allocation. He further added that very few alternative models could generate result without comprehensive data on input price which could be considered as one of the major limitations.

There had been several supply and demand studies to scrutinize a long–term supply of the agricultural commodity in the era of climate change (Furuya *et al.*, 2010; Kobayashi and Furuya, 2011). To follow the basic structure of Furuya *et al*. (2010); Kobayashi and Furuya (2011) model, the proposed piece of research had been attempted more purposively to construct area response function which was shown in details in the chapter of the conceptual framework and theoretical model.

1.7 Climate Adaptation policies in Bangladesh

Global and regional climate changes would have an enormous effect on the crop yield (Siddika, 2013). The magnitude and pattern of effect were not exactly specified. Evidence of researches perceptibly claimed that global climate constantly would evolve. Furthermore, global impact modeling (GIM) studied the desperate impact of climate change on the global market from possible climate scenarios and sensitivity approach. The model further denoted that tropical regions would be detrimentally injured, temperate would be slightly risen, and high latitude regions would be sufficiently benefited (Mendelsohn and Williams, 2004). Agrawala *et al*. (2003) had a different opinion that the impact of climate change could be measured in the trade off approaches. It could be denoted that possible adverse and beneficial effect of climate change might have a counter balance on crop production. Other study had been pointed out to combine all perceptions of the climate related vulnerability that was being emerged to be common phenomena in most of the developing countries. All vulnerable developing countries could be characterized to be more limited resources endowment, inadequate infrastructural facilities, and the weakest governance systems (Ayers, 2011).

There were many ways to address the climate change and variability. Climate change that would continue to happen and global surface temperature would continue to increase. As a result, frequency and severity of extreme events which were regularly experienced to increase and of which were the devastating cyclone, unfortunate flood, and unexpected drought. Climate change had also the adverse effect on the quality of water resources which was predicted to happen due to soil erosion, deforestation, and salinity effect coupled with sea level rising. Therefore, climate change persistently decreased the optimal farm productivity and increased pest and diseases attacks to crops (Rubaiya, 2016). Despite technological progress in crop productivity, rising global temperatures would affect the stability of crop yields and market prices (Master *et al.*, 2010). On the other hand, technological development and diffusions had been great limitation due to institutional weakness, insufficient resources as well as the lack of skilled men power (Asaduzzaman *et al*. 2010). Subsequently, climate change would have tremendous social, economic and ecological effect (Rubaiya, 2016). These all that were highlighted on the consequences of climate changes in the coming up decades and that might have been helpful to the vulnerable people and policy makers. In addition, policy makers would be ahead to make suitable policy to diminish the consequences of climate variability. More recently, adaptation to possible climate change were getting tremendous concern across national or even local level–more certain emphasis should been given to the most exposed society (communities and individual), and to industries and agricultures too.

A range of strategies was obviously crucial to climate adaptation which constituted the financial response, wider support network, changes in farming practices and informative awareness about climate change (Harmer and Rahman, 2014; Bhatta *et al*., 2017). A huge construction of the shelter for victims (human and animals), technologies generation and rivers' embankment had been merely given a central focus for adaptation strategies in public forums in Bangladesh (Ali, 1999; Amir and Ahmed, 2013; Anik and Khan 2012). Rawlani and Sovacool (2011) also pointed out that technological adaptation was in itself only partial part of a successful effort to adaptation. The integrated and comprehensive or holistic adaptation measured that incorporated the multidimensional approaches needed to make meaningful adaptation effort. Each part of climate problem that, more recently, became popular topics of debate headed to go over the shoulder of policy maker's responsibility. Systematic policy analysis should be undertaken to identify the fundamental area of intervention and ensure the access of foodgrain to the resources poor people in the era of climate change (Rubaiya, 2016). Recent days, the studies related to climate adaptation were given more important in the most vulnerable country like Bangladesh. With great emphasis, most of existing researches had been highlighted on technological generation and diffusion, development of infrastructure and increasing the awareness of climate information. There had been a dearth of studies that desperately focused on the adaptation policy as concerned with the food market in Bangladesh and that also would develop the perceptions regarding the necessary budget to secure sustainable food policy.

1.8 Food policy in Bangladesh

Movement of food prices, which always showed a complicated phenomenon, had mostly been steered with private sector behaviors (closely connected to food production, consumption, storage, and marketing) as well as government interventions (through procurement, import, stock management, and distributions). The dimensions of public food policies could be effectuated to encourage the adequate production activities, to intervene in the food market when the situations appeared to execute, and guarantee available food at purchasing capacity. Therefore, the major food policies, which continued to be executed through procurements and distributions, had been appeared to affect the market price of the food sector. In retrospect, the imported food grain in Bangladesh could be illustrated by the government monopoly before the 1990s. After liberalization allowed the private sector to participate in food grain trade and contributed greater degree to increase the availability of food grain at a stable market price(Dorosh and Shahabuddin, 1999).

Stabilizing market price was central motivation in the desk of food policy which was tremendously important for both producer and consumers. With the uncharted rise of input price even more than output price, even though modern technology dramatically boosted up the productivity, huge price shocks caused big challenges to optimize benefit for farmers. In addition, the unexpected price shock increased farmers' uncertainty and prevented them from the investment of huge effort in farming. On the other hand, rapid price hikes drastically reduced the real income of the consumer (Dorosh, *et al*. 2001a; Timmer, 1989). This was typical and classical concern that frequently became the popular debate in food policy forum. In essence, rational food policy should be executed in the way the realized benefit could be shared with the consumers without hampering the producer incentives. After all, with political and social justification having persistence role on stable food supply, the government must have an existence in food market with their sound food policy that must be devised to ensure the farmers 'incentive who continued sufficient production and to increase consumers' access to food through the increase in purchase ability.

However, the National Food Policy Plan of Action (2008–2015) in Bangladesh emphasized on the effectiveness of procurement program and provided effective support to enhance producers' income. Ensuring the stable price to consumers was another pledge of the Action (2008–2015) through the public food distribution program. This section attempted to focus on the performance of government food policies through the previous studies and dug out realistic answers to the important questions whether to impact on the target beneficiaries through execution of the food policy and provided the further avenues for policy research in the era of climate change. At the beginning in this section, tools of public food policy system in Bangladesh were briefly described as follows:

1.8.1 Public Distribution

Public food operation is not a new issue. It has a fairly long history. Public food distribution was first introduced in undivided Bengal in 1943 during the great famine due to disruption of food import from Myanmar during the Second World War and crop damage caused by fungus diseases, respectively (Sen, 1981; Ivanic and Martin, 2008). Since its inception, the nature and functions of the public food system had evolved many times over the last several decades, and was finally given the current shape of the public food distribution. At that time, it was called ration system. The British government passed an order pertaining to foodgrain enquiry and control in 1943. Simultaneously, the Department of Civil Supplies set the statutory ration for urban areas, and in 1944, modified ration was initiated for rural areas. After the partition in 1947, rationing was retained in East Pakistan. Eventually, this rationing system was abolished, leading to the introduction of the public food distribution system, which required sufficient storage and procurement activities. In the 1960s, the government procured foodgrains from large-scale farmers at a fixed price as a levy. During the 1970s, the levy system was replaced by voluntary sales to the government (Ahmed *et al.*, 1993). Public storage was built from domestic procurement and imports in order to meet public distribution needs. Public food distribution operations were expanded in the 1970s and underwent important changes in the early 1980s. Public storage capacity had been lifted to 1.7 million tons until 1985 and outspreaded throughout the country (Ashraf, 2008). Public food distribution started decreasing in the 1990s after private traders were allowed to participate in food trade under trade liberalization in 1992. The government still played an important role in food price stabilization. Impacts of high food prices on consumers were a key motivation for public stabilization schemes in developing countries. Every government held a fixed quantity of “emergency” stock and released it to the market to keep prices from abrupt upsurge.

1.8.2 Procurement activities

Changes to public food distribution operations had been accompanied by several procurement-related modifications, and these had been occurred over a fairly long time period. The National Food Policy Plan of Action, that was expected to play the most a vital role, had been amended again in 2006 to emphasize support to producer prices and to ensure stable prices for consumers. In Bangladesh, this procurement program had not been compulsory since 1983. Compulsory procurement, in conjunction with cordoning and movement controls, became an instrument in the battle to control smuggling until the late 1970s. During the first big voluntary procurement drive, the Ministry of Food (MOF) procured foodgrain directly through Temporary Purchase Centers (TPCs) by renting private warehouses and indirectly through Approved Grain Dealers (AGDs). In the second procurement surge, which lasted until the early 1990s, the MOF relied on millers to procure paddy and mill it into rice. In theory, the millers were supposed to pay the government's procurement price to farmers and charge only a fixed milling commission. Since the late 1990s, the government began procurement at a fixed price that was close to the market price. The government decided the national fixed price of rice based on costs estimated by field surveys and announced the procurement price just before the harvesting period. Farmers voluntarily could sell paddy during the announced period at the procurement centers on a first-come-first-served basis. Therefore, procurement and food distribution would be the major policy tools to implement the food price stability policy and to ensure national food security.

The government of Bangladesh attempted to control the domestic market of foodgrain through limited procurement (2–4% of production) and distribution (2–7% of demand). The main goal of public food operation in Bangladesh was to stabilize the price of foodgrain since extreme price hikes needed the larger share of daily expenses for food and lead to cutting back what they spend on other necessities (Dorosh and Shahabuddin, 1999). The procurement is meant to boost producers' incomes through the price support by government and the public distribution was intended to subsidize consumers through increasing the supply of food grain in the retail market (National Food Policy Planning Action, 2008). The related existing researches, those have been related to food policies implemented by government in Bangladesh, are reviewed as follows.

Sattar (2011) examined the efficacy of public food operations in Bangladesh with a special emphasis on rice and paddy procurement. He markedly justified the participation of farmers in procurement program with the expression $P_{GQRt} > SFP_m + r$ where, SFP_t was the open market price; P_{GQRt} was the price declared by the government in order to procure paddy and r was the risk premium which only happened if the procurement center refused to buy. Farmers only could sell their products to the government when procurement price should be existed more than market price and the risk premium must also be covered. In some case, informal payment P_i must be covered and the procurement price ought to be $P_{GQRt} > SFP_t + r + P_i$. He also tested the magnitude of the relationship between market price and the government declared price using double log–linear regression. To escape from the serial autocorrelation problem, he controlled log world price of rice and lagged market price. Therefore, the restricted regression was

$$LnSFP_t = a + bLnP_{GQRt} + \varepsilon_t \quad (1.2)$$

and the unrestricted regression was

$$LnSFP_t = a + b_1 LnP_{GQRt} + b_2 LnSFP_{t-1} + b_3 LnWPR_t + \varepsilon_t \quad (1.3)$$

where, SFP_{t-1} was the lagged market price; WPR was the world price of rice in the time period t ; and ε was the random error. a and b were the parameters of the defined independent variables. This study merely pointed out nothing more than the significant influence of procurement price over market price with a simple theoretical text and added two more points of discussions regarding which could be described as success and failure in the implementation of procurement activities. Likewise, Shemu (2013) inquired the success of procurement program through field survey in a famous divisional city areas "Mymensingh" in Bangladesh. She stated that farmers could directly sell their paddy to the government and millers could also sell their clean rice at retail price. The author enumerated several unpleasant comments of the respondent toward effective execution of this program. Ashraf (2008) examined the theoretical effect of procurement policy of rice on producer incentives. The analysis implied that the public procurement policy unlikely could transfer the benefit to the rice producers through the quantity of procurement that had been targeted to stabilize market price even in the short run.

Alam *et al*. (2014) also examined the effectiveness of the procurement program on producer's income and adequate rice procurement for public distribution requirements through the household survey. They further evaluated the behavior of private storage that would have been carried on the basis of market speculation. Stock change model was designed based on neoclassical utility maximization that indicated the farmers' behavior to carry private stock of foodgrain which could be expressed.

$$STC_{it} = \alpha_s + \beta_{si} X_{it} + \varepsilon$$

(1.4)

where, STC_{it} was the seasonal stock of the farmers; $X_{it} = (x_{1t}, x_{2t}, ...x_{nt})$ was the vector of independent variables; i and t indicated farm households and cropping seasons, respectively. Moreover, price linkage was designed as the linear models that specified the relationship between procurement price (P_{GQRt}), public stock (STC_{PBt}), and open market price (SFP_t).

$$SFP_t = \beta_p + \beta_{pi} P_{GQRt} + \varepsilon_t \qquad (1.5)$$

$$SFP_t = \gamma_0 + \gamma_{PBi} STC_{PBt} + \varepsilon_t \qquad (1.6)$$

where, β_{pi} , γ_i and β_{PBi} were the parameters that specified the casual relationship between open market price, procurement price, and stock carrying.

The increased production enormously stimulated the farmers to hold a larger stock. Price seemed to be the key signal that continued to influence the stockholding behavior of producers. They tested out the relationship between average procurement price and market price to be negative meaning that if market price tended to increase, the quantity of procurement moved to decrease. To reconfirm the seasonal behavior of the price, the relationship between procurement price and market price in *Boro* season (irrigated rice) would be found in the same direction, more specifically they were positively correlated. They further stated that procurement could contribute very weakly to market price stabilization. To conclude with, the procurement was found to be only meaningful policy content to support farmers when the market prices of farmers' product would be needed to support.

Dorosh and Shahabuddin (1999) highlighted on the mix dealings of private and government sector in the food markets and examined alternative strategic policy options through trade liberalization and procurement program to stabilize the market price of food grain. Based on the national statistics on food sectors and chronological price information, they explained the movement of long–term price in the domestic market and compared with price trend in the world market. Before trade liberalization, the fluctuation of domestic market price seemed to be substantial and completely insulated from the movement of world market price. Since the liberalization in the 1990s, the participation of private trade contributed extensively to increase food availability during constant shortage and to stabilize domestic market price that could be connected with the movement of world market prices. Thus, trade liberalization saved huge public expenses that must be expended from the national budget before. In spite of the strong positive experiences with the private sector import, the public stock must not completely be eliminated. Public sales at the subsidized price should often be needed when the market price would be unacceptably higher than consumers' ability. Besides, they denoted that the public procurement could slightly influence the domestic market prices and cover a very small proportion of the target farmers. Following bumper harvest happened to require higher support price and subsequently lead to imprudent allocation of the food budget. In the same work, they also added the review of many a great research papers of which had been accomplished by Goletti *et al.*(1991), Brennan (2003) and Ahmed and Shams (1994); those had been pointed out on the optimum stock policy of food grain in Bangladesh that were further delved to figure out the impact of public stock or private stock on drawdown of the price variations. Changing path of optimal stock accompanied by trade liberalization in the 1990s provided a big ground for market stability in the period of food grain shortage. Almost all studies seemed to be very older works which had yet not lost its importance and those could be a solid ground to endow with far more complete understanding and to extend the ideas for further research.

Goletti *et al*. (1991) worked on the optimal stock policies which had been constantly and intensely demanded by donor agencies and policy makers in Bangladesh. They had translated the effective policy frameworks into the mathematical terms that could minimize the cost of the optimal stock policies, and that could stabilize the market price and pledge the food security of the poor. After that, they moved deliberately to the comprehensive model of a policy system wherein the optimization or minimization approach had been conducted by the dynamic food policies coupled with the well–defined objectives and the policy constraints. With the explained policy framework, a cost effective and optimal stock policy had been designed to address the big concerns, regarding the cost minimization of optimal stock that could be carried to ensure the stable price and guarantee the food security of marginalized groups. Another point of discussion got a more concern in the study, of what had been highlighted on the construction of procurement and private stock function using profit maximization approach. Government procurement was constrained by the objectives and willingness of the farmers who were ambitious to maximize profit. Moreover, selling paddy to government had been dominated by the quantity of marketable surplus and difference between market and procurement prices. Similarly, private stock could be carried to maximize the profit from price speculation of the private stocks.

They had computed six different policies that were much related to the estimates of optimal stock policies and price stabilization. Those were price band policy, optimal price stabilization, import policy approach to price stabilization, cost minimization policy, price stabilization combined with cost minimization, and approximation to optimal price stabilization. The estimation of optimal policies was ended with a no–rationing policy. The policy of price stabilization simultaneously, that was combined with the cost minimization, appeared to be the best options and were further suggested to improve by the ration elimination. In addition, they enormously suggested import policy, open market purchase and open market sale, which would also be appeared to be more judicious.

In general, their study concluded that procurement in the 1980s and 1990s were abnormally high because of the excessive reaction of government to replenish the stock than to provide support price to farmers. Minimizing the price variation around target price could be achieved perfectly with the expenses of roughly half of policy cost in the baseline through the intensive open market sales and domestic procurement implementation. The flexibility of policy options would allow the utilization of advantage from domestic and international food grain market. Ignoring the rigid price band policy substantially reduce the level stock and its cost approximating to the optimal price stabilization.

Another study by Goletti (1994) examined the role of government interventions that brought the expected changes on markets conditions especially when the country would be gone in the line of rice self–sufficiency. This study had been designed and formalized the model on market integration, price effect on poverty and swap of world food market by using partial equilibrium model of domestic food market coupled with policy environments. Even though the effect of price stabilization on the market integration policy was more complicated to explain, domestic food markets were noticed to be spatially well integrated. The study also attempted to predict market price under the assumption of high, medium and low growth of the exogenously fixed factors such as population, income, crops yield as well as procurement. Both to support price through domestic procurement in peak harvest period and to reduce price shoot up through open market sale in the lean period had appeared to have almost negligible result on price control. In addition, the economic welfare of both producers and consumers that could emerge from price stabilization policy was enormously below the desired level. Therefore, implementation of price stabilization could improve neither level of extreme poverty nor nutritional status. The study only concluded the distribution of poverty was little affected to eliminate the extreme deviation below the poverty level. On the contrary, the study proposed that the high quality of Bangladesh rice could have the prospect of what would be regarded as a comparative advantage to compete in the international foodgrain market.

Brennan (2003) had parameterized the model to measure the effect of public policy on the incentives of private stock holding in Bangladesh and evaluate the transformation of its consequent effect on price stabilization in the market. The basic empirical model with the consideration into a closed economy which, he dedicated to design, had been motivated by rationale expectation using dynamic programming techniques. As such inter–temporal arbitrage rule had been committed to adjust the quantity of storage ($STC_t \geq 0$) and thereby equating between marginal value (RPR_t) of the current consumption (DDR_t) in period t plus cost of physical storage (k) including interest (r) and the expected value ($E[RPR_{t+1}]$) of consumption of that stored unit in the following period $(t+1)$ as expressed below

$$RPR_t + k \geq \frac{E[RPR_{t+1}]}{1+r} \tag{1.7}$$

The market supply model (NSR_t) had been defined based on the rational expectation of producer prices (SFR_t) and random yield (YR_t) and this could be written as follows

$$NSR_t = f(SFP_{t-1}(STC_t))YR_t; \quad f'(SFP^r) > 0 \tag{1.8}$$

where, $SFP_{t-1}(STC_t)$ was indicated by producer incentive price and the random yield (YR_t) had mean ($\overline{YR}$) and standard deviation (σ).

He also expressed market prices (RPR_t) as the function of total consumption (DDR_t) in the same period as follows.

$$RPR_t = g(DDR_t); \qquad g'(DDR_t) > 0 \tag{1.9}$$

The market clearing condition could be defined in the following expression

$$DDR_t = NSR_t + STC_t - STC_{t-1} \tag{1.10}$$

Price, which was assumed to be affected by rational expectation, depends on storage carry–out and in turn, would be affected by anticipated storage in the subsequent period. Therefore dynamic programming approach was employed to estimate expected price ($E[RPR_{t+1}]$).

$$E_t[RPR_{t+1}] \cong a_0 + a_1 STC_{t+1} + a_2 STC_{t+1}^2 \tag{1.11}$$

He also extended the model with an open border of the economy for market price stabilization through international trade. The state variables in the model included domestic storage and the world price of the commodity which could be stated in the following.

$$RPR_t(NSR_t + STC_{t-1} - STC_t + IMP_t) + k \geq \frac{E[RPR_{t+1}(STC_{t+1}, WP_t)]}{1+r} \tag{1.12}$$

$$NSR_t = f(SFP_{t-1}(STC_t, WPR_t))YR_t; \tag{1.13}$$

$$\left| RPR_t[NSR_t + STC_{t-1} + STC_t + IMP_t] - WPR_t[IMP_t] \right| \leq T \tag{1.14}$$

$$WPR_t = \phi WPR_{t-1} + cIMP_t + \varepsilon \tag{1.15}$$

where, WPR_t was the world price in the period t; ϕ was the serial correlation of world price; IMP_t net import, ε was disturbance term for world price; c was the impact of Bangladesh imports on world prices ($c > 0$); and T was the cost of trade.

The study conducted a comprehensive simulation with the explained dynamic programming techniques. The simulation analysis showed that there had been very low incentive for private stockholding due to high storage cost and the elastic demand which in turn strongly validated to take the public stock policy. A more elastic demand for a commodity reduced the incentives to carry stock and refers to the reason that quantity of consumption might be substantially varied compared to consumption of the inelastic commodity. The public intervention could be justified based on the ground that there had been a persistent disincentive to private storage where the infrastructure might be developed very poorly. On the contrary, removing disincentive was much cheaper than public direct intervention. Disincentive could gradually be removed when the provision for good infrastructure in private sector, direct subsidy on private storage and suitable interest rate would be undertaken through incentive policies toward private sector. Moreover, the economic study of open border indicated that incentive to private stockholding greatly declined referring to the fact that production of Bangladesh was not perfectly correlated with world production. However, the public stock policy was not separated conceptually from welfare policies that protect the poor households from an impact of extreme price hikes. He finally referred to other studies that targeted food rationing schemes might be alternative to food price stabilization. This might be reason that market of inelastic demand would be made fine-tune based on purchase and distribution of poor people with the targeted rationing food schemes and that could also increase the incentive of private storage.

Islam and Thomas (1996) designed and analyzed several objectives related to food price policy including the effect of price stabilization on producer and consumer benefit at the micro level as well as macro level including social and political stability. The micro level analysis incorporated the analytical framework coupled with risk aversion assumption of 0.5, 1.0 and 1.5 based on profit maximization approach of expected utility. The macro level approach used the supply and demand model in a single or open economy under the assumption of partial equilibrium. This study mainly paid attention to the operational aspect of policies in five Asian countries namely Bangladesh, Indonesia, Pakistan, Philippines, and Thailand. The effectiveness of price support to both producers and consumers depended on a number of closely interrelated things: First a wider gap between floor and ceiling that allowed private traders to make a profit. Second the timely, adequate public procurement and release of stock were associated with the availability of financial arrangements. The micro level analysis yielded the economic benefit of price policies with and without risk aversion assumption that appeared to be smaller. The macro level of price stabilization analysis explored inadequate benefit coupled with the big concern for social and political issues. This made the debate among the policy makers to continue the price stabilization with the objectives of various success and huge cost involvements.

Saeed *et al*. (2000) examined the roles that were usually played by producers, population, and government in order to make the availability of food in Bangladesh. System dynamic model of food–population systems were used to achieve the objective of this paper. Nationwide time series datasets were used. In short run policy intervention, agricultural growth and population control measure could promote per capita food consumption. Oppositely in long run, none of the policies to be intervened could improve or alleviate the shortage of food. This study placed the question reading effectiveness of rationale agricultural policies in enhancing food availability in the long run.

There had been an old and classical debate about success and effectiveness of public food policy that would have been implemented in the event of a bumper harvest and extreme food crises for both farmers as well as consumers. Many welfare economists were against the public stabilizations policy and stated that this policy was economically ineffective and wasteful. Contrastingly, the debate of this policy sometime was answered by some economist such as Ravallion (1997). He remarked that price stabilization policy could reduce the number of famine victims that happened to be the great evidence in 1943 or 1974 great famine which claimed more than million people. Price stabilization had political and economic emphasis, was the reasons that rapid price rise was believed to be the failure of the government to ensure the food security. Therefore, price instability continued to strongly motivate the government to support the farmer by influencing market price and put a down pressure on the consumer price through the public intervention in the food market (Dorosh and Shahbuddin, 1999). Most of the developing regions had been carrying out food operation activities to control the price instability that took place from foodgrain supply shock. Ahmed and Bernard (1989) advocated in favour of stabilization policy that could protect farmers from low market price and poor households from the adverse shock in the event of price skyrocket. Moreover, private players in the food systems were important functionaries, who usually made an effort to maximize profit from the price speculation that was, without doubt, contributed to mitigate the price instability. The individual player was not adequately able to mitigate the price variation effectively to farmers as well as to consumers. That’s why, combined with private effort, the state needed to play a role simultaneously in the market to ensure the rational access to foodgrain, even in the era of climate change.

1.9 Remarks

A single piece of research should not be expected to integrate all issues to come up with all possible answer. There were a good number of researches that were reviewed and those had been dealt with a specified problem and come up with corresponding answer. In the proposed research, an attempt had been made to figure out the effect of changing climate variables on the market structure of rice in Bangladesh and to derive a needful and successful adaptation policy instruments to minimize the adverse effect to the producer as well as consumers. Moreover, impact analysis of climate change on foodgrain market became increasingly popular using econometric approach to explain the market structure, behaviors of producers and consumers, determination of market price and policy performance more particularly to support the policy makers regarding policy budgeting, traders, think tanks and researchers to project future market situations in the course of climate change.

CHAPTER–II

CONCEPTS AND THEORETICAL MODELS

2.1 Concept and Impact of Climate Change

In order to address the research concepts, this chapter started with an approach of supply and demand as well as highlights on concepts of market response to climate change. This chapter also attempted to construct supply and demand model from the theoretical inferences.

The marginal cost of production goes up with an increase in production. The upward sloping curve of LMC (green line) that can be illustrated by increasing production cost per unit and adding each unit increases to total output, usually interpreted to supply curve. Climate variables likely cause a shift of marginal cost curve in long–run. Figure 2.1 has been pointed up by a change in the extent of production that happens to produce and subsequently affect the marginal cost of production. In figure 2.1 where, QR_0, QR_1, and QR_2 are illustrated by the quantity of production that is assumed to be changed. In short–run, possible variation in production might be stimulated by climate shocks.

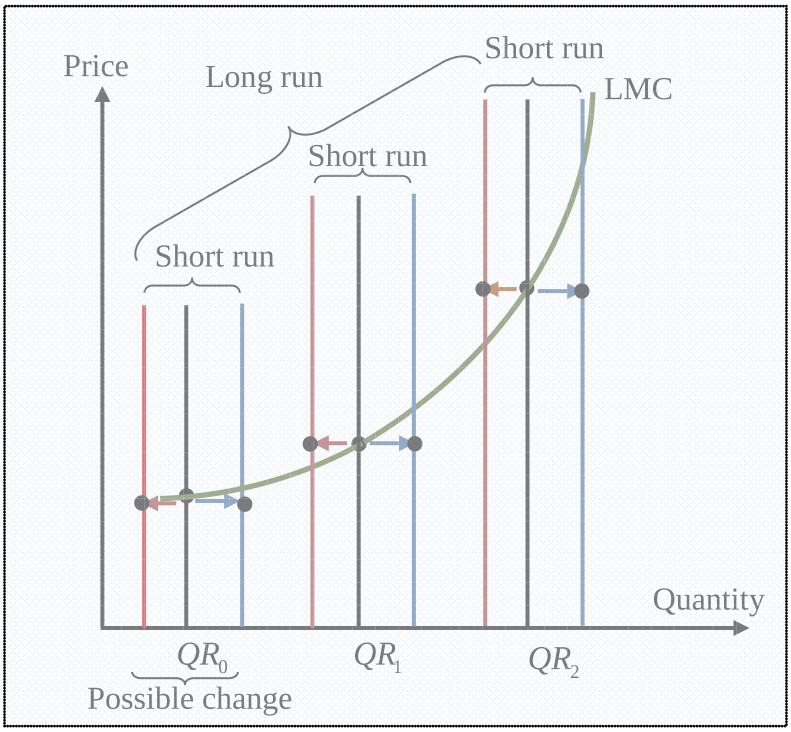

Figure 2.1 Change of marginal cost with changes in production

Due to variation in short–term production, change in long–term marginal cost curve, which is indicated by LMC in figure 2.1, is also presumed to occur. The change in production and subsequent change in LMC can be denoted by forward (blue line) and backward arrow (red line) bars in figure 2.1.

Undoubtedly, climate change has an enormous shock on agricultural farming including production, cost involvement and productivity leading to increasing variation of the food supply, market price variation and food demand; in particular, effects will be more challenging in poorly developed countries in the coming decades (Master *et al.*, 2010). Thus, due to changing drift in climate, the convergence of supply and demand emerges to be abundantly irregular that, in turn, causes a greater degree of variation in market price.

Since the inception of the industrial revolution, the rapid emissions of GHGs instigate to concentrate and continue to alter the atmospheric configuration. Now–a–days, advance climate research could be able to quantify the magnitude of adverse impact on global warming, more specifically treacherous consequences such as high temperature, melting glaciers, sea level rise, and extreme events that persistently bring about the changes in crop productivity. Therefore, the global food system is increasingly getting drastic threats to climate changes. Furthermore, increasing temperature promoted by rapid accumulation of GHGs is likely to pose unavoidable threats on stable and sustainable global food supply (Paul *et al.*, 2016).

The rapid growth of economic activities in Asia results in a high emission of Green House Gas (GHG) (mainly CO_2 emission) as projected to exceed 60 percent of global total emission by 2100. So rapid emission increases the temperature, shapes strength and timing of monsoon, speeds up snow melt and shortens winter in Himalayas regions (Masui *et al*., 2011). It is a prerequisite to carry out the research absolutely related to the impact of climate change on food sector even for individual countries so that ever meaningful information could be produced to decision makers about various suitable strategies, they must adopt those to continue stable foodgrain production and protect the hunger from the adverse effect of climate change. As such potential climate shock on rice market could be imagined to be depicted in figure 2.2. It implies that the climate change determines the various levels of rice supply and thereby causing the market price to vary the higher extent in the future food market.

Assuming the production under normal climate as an average situation at QR_0 in figure 2.2, favorable climate positively induces domestic supply which is denoted by increasing supply to S_{IN} (blue line). The actual harvest is as much as the amount indicated by QR_{IN} in figure 2.2. In contrast, the negative effect of climate change induces the actual harvest to decline to the amount indicated by as much as QR_D and the supply curve shifts to S_D (red line) from original supply curve (S_0) (black line).

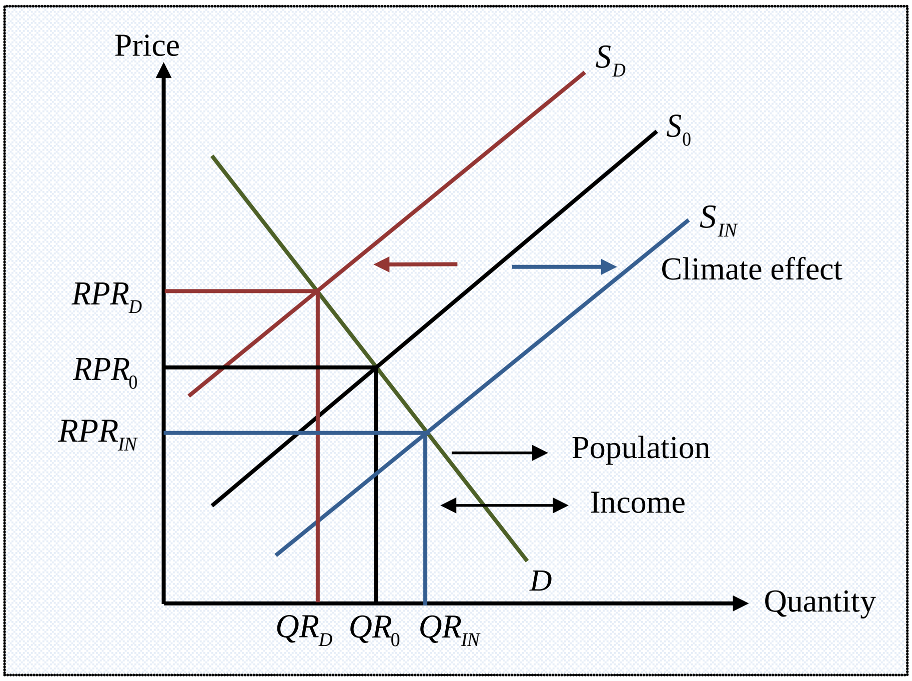

Figure 2.2 Reflection of climate effect on the supply and demand determination.

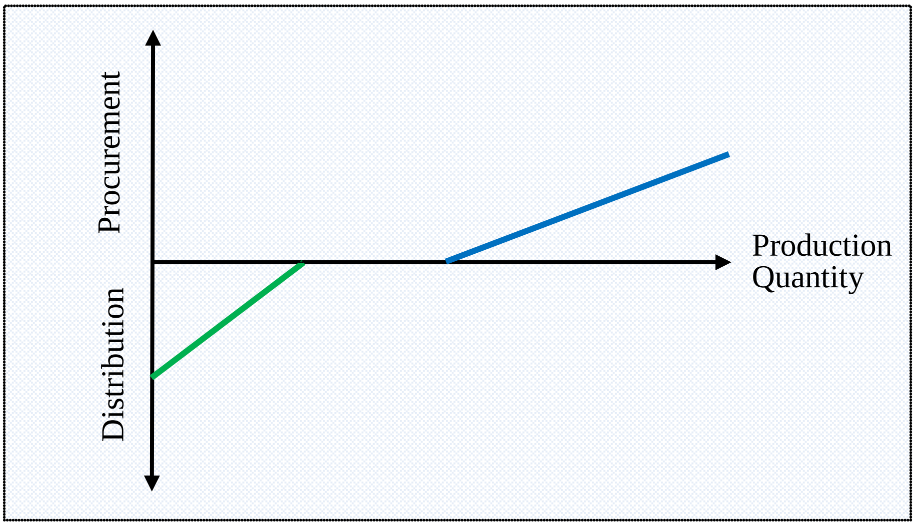

Figure 2.3 Food policy operations with the quantity of harvest

Therefore, the evaluation of climate change is becoming the most important matter to sustain the food market in Bangladesh through fixing the unexpected impact.

In addition, figure 2.2 shows the effects of climate change on the fluctuation of market price. Demand curve (D) (green line) is also proposed to be affected by population growth and change in income. Every equilibrium point is achieved through the various supply and demand convergences that can be written in the expression as below:

$$\text{At } RPR_D > RPR_0 > RPR_{IN} \text{ where } S_D = D_D < S_0 = D_0 < S_{IN} = D_{IN} \qquad (2.1)$$

Accordingly, with the variation of market prices, producers will change their decision to adjust the market response and consumers rearrange budget expenditures:

- If the price rises, producers will extend their production activities and the supply will be going upward. The slope of the supply curve is positive.
- If the market price rises, consumers tend to decrease their consumption and the demand will be going downward. The slope of the demand curve is negative.
- At market clearing price, the difference between supply and demand is zero.

Under the policy adaptation framework, the policy makers as well as the state planners might be compelled to keep an uninterrupted rice supply. A convenient rice market should be regulated in the proper way that functions smoothly in order to encourage sufficient production as well as sales at the reasonable price, and to ensure the purchase of the marginalized groups within the buying capacity. Food policies would be implemented through procurement that boosts up producers' income and public distribution that reduces the price hikes shock for consumers. Figure 2.3 exhibits the magnitudes of food operation during variation of market supply to influence the market price.

It is repeatedly true evidence that global climate continues to evolve and weather of which components namely temperature, rainfall, solar radiation, and humidity will be altering at the faster rate. Recent days, to experience more visual changes in climate that might increasingly be a tremendous concern in the desks of global think tanks. In addition, human beings continue to face climate consequences of food crises which, in sequence, trigger food price variation to a greater extent in the coming decades. In an apparent imaginary, it is believed that variation of rice yield could be determined to illustrate a degree of climate shock whereas demand is subject to price change, the growth of population and income level.

Therefore, a solid proposition on various level of rice harvest and different extent of price variation are getting ever more priority that might be attributed to the effect of climate change. All these things that together robustly motivate to undertake the present study regarding the impact of climate alteration on the outlook of rice supply and demand in Bangladesh.

2.2 Theoretical Model of Supply Function

2.2.1 Definition of production function

In definition, production function gives different inputs combinations that produce the maximum level of output. Production function, furthermore, means a functional relationship between physical inputs of production and physical output of a farm. The technological relationship between quantity of inputs and maximum possible output of the products is called production function (Coelli *et al*., 2005; Henderson and Quandt, 1980).

2.2.2 Construction of profit maximization

The producers, who are assumed to be more judicious, have a strong motive to maximize the profit through maximum production using the optimal combination of inputs given the factors and output prices as well as technologies. SFP refers to farm gate price of output and W_x represents the price vector of inputs ($1 \times N$) which is assumed to be given. This is because the producers are sellers just as price taker under the perfectly competitive input and output markets.

Therefore, they cannot have control over market prices and they must sell their products at the market clearing price. Profit function of a rice farm that can be maximized subject to the production technologies denoted as follows:

$$\left.\begin{aligned} &\max_{QR,X} \Pi = QR \times SFP - W_x \times X \\ &\quad \text{Subject to } F(QR, X, Z) = 0 \\ &QR > 0, X > 0 \end{aligned}\right\} \qquad (2.2)$$

The profit function is assumed under the following assumption:

(1) Non-decreasing in SFP

(2) Non-increasing in W_x

(3) Convexity and continuity in SFP and W_x

(4) Homogeneous of degree one in SFP and W_x.

The formulated Lagrange function from equation (2.2) for the constrained profit maximization approach is displayed as:

$$L\left(QR, X\right) = QR \times SFP - W_x \times X - \lambda F\left(QR, X, Z\right) \qquad (2.3)$$

Taking first order condition (FOC) of equation (2.3) with respect to inputs and output including the Lagrangian multiplier (λ), and setting them equal to zero ensures a local maximum.

$$\left.\begin{aligned} &\partial L/\partial QR = SFP - \lambda F_{QR} = 0 \rightarrow SFP = \lambda F_{QR} \\ &\partial L/\partial X = -W_x + \lambda F_X = 0 \rightarrow W_x = \lambda F_X \\ &\partial L/\partial \lambda = F(QR, X, Z) = 0 \end{aligned}\right\} \quad (2.4)$$

The maximum profit point is the tangency of the slope of iso–profit curve and slope of production curve as defined below:

$$\frac{W_x}{SFP} = \frac{\partial QR}{\partial X} \quad (2.5)$$

Applying and solving the system of equation (2.4) simultaneously yields the optimum supply and factors demand function. They can be written as follows:

$$QR^* = (SFP, W_x, Z) \quad (2.6)$$

$$X^* = (SFP, W_x, Z) \quad (2.7)$$

The derivation of first order condition ensures the necessary condition. Again, to meet the sufficient condition that ensures the local maximum point, the bordered Hessian matrix of second order is required that has an alternative sign. The special border Hessian matrix can be expressed as follows:

$$(-1)^{N+1}\begin{vmatrix} \Pi_{11} & \cdots & \Pi_{1,N+1} & \Pi_1 \\ \vdots & \ddots & \vdots & \vdots \\ \Pi_{N+1,1} & \cdots & \Pi_{N,N+1} & \Pi_{N+1} \\ \Pi_1 & \cdots & \Pi_{N+1} & 0 \end{vmatrix} > 0 \text{ and the principal minor is } \begin{vmatrix} \Pi_{11} & \Pi_{12} & \Pi_1 \\ \Pi_{21} & \Pi_{22} & \Pi_2 \\ \Pi_1 & \Pi_2 & 0 \end{vmatrix} > 0$$

Both the derivation of first order conditions and bordered Hessian matrix satisfy the necessary as well as sufficient condition that ensures the profit maximization, respectively.

The purpose of this study is to formulate the functions for seasonal disaggregated variables. The seasonal disaggregated supply functions are derived from aggregated profit function as follows:

$$\sum_{i=1}^{3}\Pi = \sum_{i=1}^{3} QR_i \times SFP - \sum_{i=1}^{3} W_x \times X$$

$$QR_v^* = (SFP, W_x, Z) \quad (2.8)$$

where, $i = 1, ..., 3$ denotes for three seasons. There are two points for selection of supply function and ignorance of input demand function: First, this present study is more completely dedicated to the investigation of the impact of climate on the partial market equilibrium of output supply and demand. To approach at the convergence point of the output, input demand function is not necessary to be estimated in the present pieces of research. Second, the availability of sufficient data assists to make a solid platform so as to estimate the derived model. The availability of comprehensive data on input price is a major constraint. In addition, it is almost impossible to estimate the input demand function because season and variety specific data on input use appears to have been a great limitation for comprehensive statistical estimation (Zohir *et al*. 2002). Therefore, the output function is solely taken and determined by explanatory factors including climate variables. Furthermore, the output could be partitioned into the area harvested and the crop yields which are more precisely noted in the following expression:

$$QR = AR_{iv} \times YR_{iv} \tag{2.9}$$

where, AR_{iv} is referred to the harvested area of paddy and YR_{iv} is indicated by the yield of paddy for two varieties ($v = 1, 2$) and three seasons ($i = 1, ..., 3$).

More specific definition of varieties and seasons:

$v = 1$: Modern varieties and $v = 2$: Local varieties

$i = 1$: *Aus* season, $i = 2$: *Aman* season, and $i = 3$: *Boro* season

To simplify the models for more special purpose and to capture a wide dispersion of seasonal variation, the seasonal area and yield function by varieties could be formulated separately.

2.2.3 Adaptive expectation approach

In agriculture, the market prices of the output determined in every previous harvest activity preside over the planting decisions of the farmers profusely in the next planting. Because of the time lag that commonly happens in the preceding period, producer price expectations are far more concern in the development of a model. There are three alternative hypotheses in agricultural that support producer expectations price in the literature such as 1. The naive expectation, 2. The adaptive expectation and 3. The rational expectation. Farmers, especially in the developing countries like Bangladesh, are mostly illiterate, and as a result, are supposed to have no good access to all the relevant information they require to decide. This study believes that adaptive expectation is absolutely right means for decision making in a supply decision that the farmers respond. Therefore, adaptive expectations delineate that the farmers employ experiences about what they come to decide in the next planting depends on what they would have already experienced in the last harvest. Furthermore, expectation behavior explains that the observed quantities may differ from desired ones due to the adjustment lag in the decision processes. Assuming that if the harvested area is equal to planted area in Bangladesh, the following planted area function will be obtained:

$$AR_t = \alpha_0 + \beta_0 SFP_t^* + \gamma_0 Z_t^* \quad (2.10)$$

The adaptive expected approach is applied to the function. The price and climate relation equation of adaptive expectation model is as follows:

$$SFP^*_{t+1} - SFP_t^* = (1-\lambda)(SFP_t - SFP_t^*)$$

$$SFP_{t+1}^* - SFP_t^* = SFP_t \text{-} \lambda SFP_t - SFP_t^* - \lambda SFP_t^* \quad (2.11)$$

$$SFP_{t+1}^* - \lambda SFP_t^* = (1-\lambda) SFP_t$$

Similarly, climate variables

$$Z^*_{t+1} - Z_t^* = (1-\lambda)(Z_t - Z_t^*)$$

$$Z_{t+1}^* - Z_t^* = Z_t - \lambda Z_t - Z_t^* - \lambda Z_t^* \quad (2.12)$$

$$Z_{t+1}^* - \lambda Z_t^* = (1-\lambda) Z_t$$

The coefficient of “λ” is defined as the Nerlovian coefficient of lag adjustment which can be quantified based on Hick’s elasticity of expectation. This specifies that the speed at which the farmers make an effort to adjust with their expectation in planting decision. The coefficient value of adjustment ranges between 0 and 1. A value of “λ” close to “0” denotes that the farmers are sluggish to adjust the changing prices. The equivalent of “λ” value to one denotes that the farmers are very faster to adopt adjustment to the changing prices and changing the climate (Barmon and Chaudhury, 2012).

The equations (2.11–2.12) are the adaptive expectation model. The left part of the equation is the updating expectation and the right part is the error in the previous period. Equations (2.11–2.12) can be rewritten with one lag is as follows:

$$SFP_t^* - \lambda SFP_{t-1}^* = (1-\lambda) SFP_{t-1} \quad (2.13)$$

$$Z_t^* - \lambda Z_{t-1}^* = (1-\lambda) Z_{t-1} \quad (2.14)$$

$$0 \leq \lambda \geq 1$$

Equation (2.12) is also expressed with one year lag and multiplying with λ as follows

$$\lambda AR_{t-1} = \lambda\alpha_0 + \lambda\beta_0 SFP_{t-1}^* + + \lambda\gamma_0 Z_{t-1}^* \quad (2.15)$$

Subtracting equation (18) from equation (13)

$$AR_t - \lambda AR_{t-1} = \alpha_0 - \lambda\alpha_0 + \beta_0 SFP_t^* - \lambda\beta_0 SFP_{t-1}^* + +\lambda\gamma_0 Z_{t-1}^* - \gamma_0 Z_t^*$$

$$AR_t = (1-\lambda)\alpha_0 + \lambda AR_{t-1} + \beta_0(SFP_t^* - \lambda SFP_{t-1}^*) + \gamma_0(Z_t^* - \lambda Z_{t-1}^*) \quad (2.16)$$

Therefore, substituting $(SFP_t^* - \lambda SFP_{t-1}^*)$ and $(Z_t^* - \lambda Z_{t-1}^*)$ by $(1-\lambda)SFP_{t-1}$ and $(1-\lambda)Z_{t-1}$ into equation (2.16) respectively, Or substituting the equation (2.13) and (2.14) into equation (2.16)

$$AR_t = \alpha_0 + \lambda AR_{t-1} + \beta_0(1-\delta)SFP_{t-1} + \gamma_0(1-\delta)Z_{t-1} \quad (2.17)$$

Assume that

$(1-\lambda)\alpha_0 = \alpha_{AR}$

$\lambda = \beta_{AR1}$

$\beta_0(1-\lambda) = \beta_{AR2}$

$\gamma_0(1-\lambda) = \beta_{AR3}$

Substituting the new definition of the parameters into equation (2.17), the following equation will be stated:

$$AR_t = \alpha_{AR} + \beta_{AR1} AR_{t-1} + \beta_{AR2} SFP_{t-1} + \beta_{AR3} Z_{t-1} \quad (2.18)$$

If the planted area responds to price and the yield does not respond to the expected price, the explanatory variable will be planted area as the exogenous variable in the previous season. At the time, the yield is independent of the expectation approach because the yield does not respond to the price. In a word, crop acreage is assumed to be mostly under farmer's control compared to the determination of output level. This is because output especially yields depend on the variability of factors like climate, soil quality, water availability and technologies (Yaseen *et al*., 2011).

In more explanation to derive the yield function, considering the climate as one of the major determinants, yield function is built incorporating climatic variables (rainfall, temperature, and solar radiation) and time trends, as used for technological progress (improved cultivars, all kind of machinery and fertilizers). Furthermore, rice yield in Bangladesh has a long–term increasing trend, which is characterized by the constant spreading of advanced technologies and support by both government and NGOs. However, the variation in yield caused by climate factors is substantially higher than variation in yield (minimal) which is attributed to farmers' decision. The functional form of yield can be mathematically expressed as below:

$$YR_i = f(T, Z) \tag{2.19}$$

The purpose of this research is to focus on the impact of climate on an outlook of supply and price variation. For this reason, it does not need to incorporate farmers' adjustment and expectation in yield function. The theoretical justification measures the farm production of rice that will be combined into the system of rice market.

From above discussion, total production has been computed multiplying area with yield, whereas domestic net supply in the market is determined by production, domestic stock change, and trade including indirect demand (Seed, Feed, Process and Other Uses). The net supply of rice in the market can be expressed by the following equation:

$$NSR = QR - STC + IMP - (SEED + FEED + PROC + EXP + OU) \tag{2.20}$$

where, NSR is the net supply in the market, STC is the domestic stock demand, IMP is the import of rice, EXP is export demand, and $SEED, FEED, PROC$ and OU are indirect demand for Seed, Feed, Process and Other Uses, respectively.

2.3 Derivation of Demand Function

In microeconomics, the study of consumer choice is highlighted to be more concern about how a rational consumer could select the commodity for consumption decisions in line with their budget constraint. An individual satisfaction consuming a particular good is also determined by the quantity of other goods that are alternatively consumed. Utility depends on the choice of goods bundles. For simplicity, it can be assumed two goods such as rice and wheat in Bangladesh case.

Rice and wheat are the primary cereal commodities which dominate consumption pattern in Bangladesh. Wheat is only substitute to rice consumption. Furthermore, a bundle of cereal food is illustrated by two commodities such as rice and wheat. The price of wheat influences the choice of quantity consumption of rice which can be represented in the utility structure. The maximization structure can be constructed using consumer's choice bundles of rice and wheat and budget constraint. Based on the consumer theory, the consumer's constrained optimization problem can be expressed as follows:

$$\left.\begin{array}{l} \max\limits_{DDR,W} U(DDR, DDW) \\ \text{Subject to } RPR * DDR + RPW * DDW \leq M \end{array}\right\} \tag{2.21}$$

where, DDR is referred to the household consumption of rice and DDW is indicated by household consumption of wheat. RPR is the price of rice per unit and RPW is the price of wheat per unit. M is indicated by the individual budget that has been spent on consumption bundles such as rice and wheat. The budget line is presumed to revolve more exactly close to income endowment. The utility is attributed by the monotonically increasing, continuous, twice differentiable and strictly quasi–concave.

The Lagrange function can methodically change a constrained maximization approach into an unconstrained problem of choosing DDR and DDW. Lagrange function of utility maximization is presented below.

$$L(DDR, W) = U(DDR, DDW) - \mu(M - (RPR * DDR + RPW * DDW)) \tag{2.22}$$

where, μ is Lagrange multiplier. Setting FOC to zero, which is derived from differentiating the equation (2.22) with respect to DDR and DDW, is as follows.

$$\left.\begin{aligned} \partial L / \partial DDR &= U_{DDR} - \mu RPR = 0 \rightarrow U_{DDR} = RPR \\ \partial L / \partial DDW &= U_{DDW} - \mu RPW = 0 \rightarrow U_{DDW} = RPW \\ \partial L / \partial \mu &= M - RPR * DDR - RPW * DDW = 0 \rightarrow M = RPR * DDR - RPW * DDW \end{aligned}\right\} \tag{2.23}$$

Solving system of equation (2.23) gives the consumer's demand per capita or Marshallian demand functions of DDR and DDW which can be treated as functions of prices and income. If these demand functions are plugged into the utility function, then again, the obtained indirect utility function is the function of prices and income only: economics theory says that demand for any commodity is the function of commodity price, substitute commodity price and income. Demand for rice (DDR) and for wheat (DDW) can be denoted by a generalized form of demand function as below:

$$DDR = (RPR, PPW, M) \tag{2.24}$$

$$DDW = (RPR, PPW, M) \tag{2.25}$$

A concern regarding converged market price is obtained from partial equilibrium model. Demand function is the core component of hindsight of the rice supply. That’s why, the most effort is purposively made to select the rice demand function from the system of the utility maximization approach. In the preceding discussion, the net supply function has been identified from total production. Now the market clearing condition for rice market could be stated from the derivation of per capita net supply and per capita demand:

$$DDR = \frac{NSR}{POP} \tag{2.26}$$

where, POP is the total population in Bangladesh

2.4 Formulation of Policy Model

2.4.1 Theorem of social welfare

An economy is considered where a market is perfectly competitive. All individuals are price-takers and they want to maximize utility which must be subject to their budget constraints. All producers are also assumed to be price-takers. There is no doubt that the purpose of all producers is to maximize the profit. Hence, Pareto Optimality is a result of rational economic behavior by producers and consumers in a perfectly competitive economy. In underlying theory, Pareto Optimality will be obtained when markets are under perfect competition and must be in equilibrium. According to the concept of neoclassical economics, "One will be better off ever meaning that someone else must be somewhat worse off" (The Teen Economist, 2017)..

As supported by Amartya Sen, "a society or an economy can be Pareto optimal and still perfectly disgusting". It means that an economy under perfect competition may be effective in Pareto sense if some people are rich and others are poorer. The poorer cannot be made better off without cutting back the choices of riches (The Teen Economist, 2017). Therefore, in the light of Pareto optimum approaches, maximization problem of welfare maximization cannot read the formulation of policy models.

In essence, social welfare may be optimum when the market condition will arrive at equilibrium. Food policy is assumed to reduce the total welfare due to a realization of deadweight loss in the market equilibrium condition.

More frequently, welfare economists speak out that price stabilization strategies are economically a great spendthrift. However, most of emerging countries have to tirelessly practice price stabilization policy which deals with a reduction of price fluctuation induced by the domestic supply shocks of foodgrains (Ahmed and Bernard, 1989).

In statistics, Bangladesh is, in general, documented as a low-income country (US$958 per capita) where a 31.5% of total people, which part is persistently under the poverty line, are extremely vulnerable to price variations (World Bank, 2017). Climate shocks, instability of production, and price variations are experienced as major reasons for the occurrence of food insecurity in Bangladesh. Policy intervention by governments is commonly accentuated toward the stable supply of food as well as lower food prices for poor households. Bangladesh always practices sets of such policy dynamics to reduce poverty and food policy is believed to be one of most essential policy effort. By the end of last decade, Bangladesh has accomplished a great task for the achievement of Millennium Development Goal (MDGs) of poverty reduction which now stands for 31.5% of total population. Still, many tasks remain to be done for further reduction of poverty under Sustainable Development Goal (SDGs). Therefore, implementation of food policy is a must to control the variation of market price in favor of the producers and consumers.

To read the policy model, first, the change in producer surplus and consumer surplus are investigated from market equilibrium condition of supply and demand. Under the intervention of support price activities, changes in producer surplus will be realized. With the intervention of an extended subsidized price policy, changes in consumer surplus will also be realized. From the implemented policy in the food market, changes in surpluses can be computed, which will elaborately be described in the following section. However, most part of this attempt is to identify the possible explanatory variables for procurement and distribution functions.

2.4.2 Changes in producer surplus and consumer surplus under policy

2.4.2.1 Changes in producers' surplus

The following assumptions are considered regarding changes in producer surplus: Total cost of production remains constant for a year (normal climate, a negative effect and a positive effect of climate on the production). That's worth repeating that average cost of production might be varied due to variation in total production. It is also presumed that farms are headed to gain almost zero profit in an average year. Supply in a normal or average year is indicated by S_0 (black line), the negative effect of climate causes supply curve shift to S_D (red line) and the rice price in the deficit year becomes SFP_D. The positive effect of climate leads to increase the production as indicated by S_{IN} (blue line) and the corresponding price becomes SFP_{IN} (Figure 2.4).

When increasing agricultural commodities goes to the market, higher supply causes market price to substantially lower. In the market mechanism, all farms are profit maximizing and only price takers.

Rice demand as a staple dietary item is usually inelastic in Bangladesh case. Therefore, the demand elasticity can be denoted as $-(\partial D / D) / (\partial RPR / RPR) < 1$ where, D is demand for rice, and ∂D is smaller change in D, RPR is the retail market price of rice, and similarly ∂RPR is a smaller change in rice price RPR.

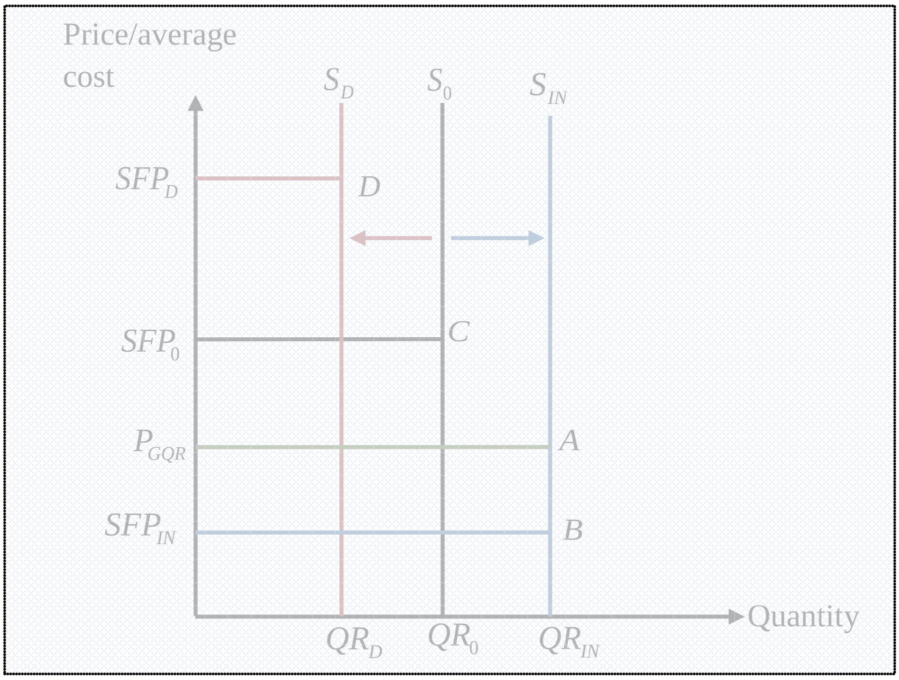

Figure 2.4 Price fall and support price policy

Taking $-(\partial D / \partial RPR) < D / RPR$ into consideration again and assuming that, where $D = QR_0$, $RPR = SFP_0$, It may be compared between an average and a good year, $-\partial D = QR_{IN} - QR_0$, $\partial SFP = SFP_0 - SFP_{INt}$.

The above equation can be presented in the following:

$$(QR_{IN} - QR_0)/(SFP_0 - SFP_{IN}) < QR_0 / SFP_0 \rightarrow P_0(QR_{IN} - QR_0) < (SFP_0 - SFP_{IN})QR_0 \quad (2.27)$$

Again, $$SFP_{IN}(QR_{IN} - QR_0) < SFP_0(QR_{IN} - QR_0) < (SFP_0 - SFP_{IN})QR_0$$ $$\rightarrow SFP_{IN}(QR_{IN} - QR_0) < (SFP_0 - SFP_{IN})QR_0 \quad (2.28)$$

Therefore, if the demand is assumed to be inelastic, a farmer's income in a good year becomes lower than that in the average year. Implementing procurement policy is supposed to enhance farmers' income as specified by $(P_{GQR} - SFP_{IN})QR_{IN}$

$$SFP_{IN}(QR_{IN} - QR_o) < SFP_{IN}(QR_{IN} - QR_0) + (P_{GQR} - SFP_{IN})QR_{IN} < (SFP_0 - SFP_{IN})QR_0 \quad (3.29)$$

Equation (3.29) exhibit that implementing the procurement activities with a higher price to market price increase the farm revenues and protect farms from incurring a loss. To simplify the amount of the government purchase, the right side of figure 2.5 demonstrates the decomposition of QR_{IN} for the famers who offer to sell the amount as indicated by QR_{mar} in the market at price SFP_{IN} and sell the quantity $(QR_{IN} - QR_{mar})$ to the government at P_{GQR} .

P_{GQR} is regarded as government purchase prices. From the above figures, right side figure is attributed to a change in producer surplus (yellow marked) that can be formulated as follows:

$$\Delta PS = (QR_{IN} - QR_{mar})(P_{GQR} - SFP_{IN}) \quad (2.30)$$

where, PS is producer surplus.

Short term supply curve Simplification $\rightarrow$ for government purchase

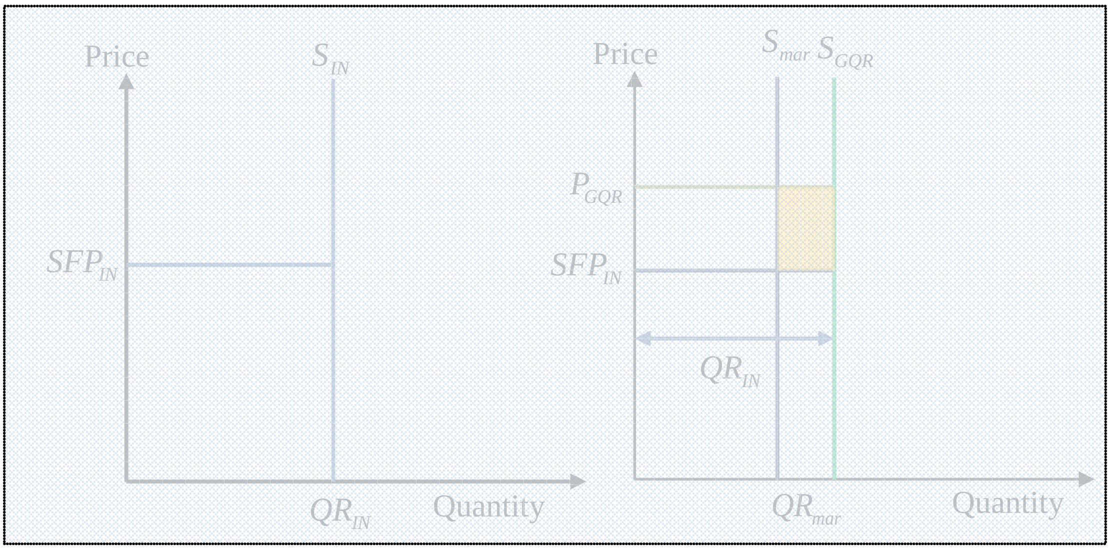

Figure 2.5 Government purchase paddy at support price

Change in producer surplus for all farms (where, $h = 1, 2, ..., n$) can be expressed in the following form:

$$W_{GQR} = \sum_{h=1}^{n} PS$$

$$\sum_{h=1}^{n} \Delta PS = \sum_{h=1}^{n} [(QR_{IN} - QR_{mar}) * (P_{GQR} - SFP_{IN})] \quad (2.31)$$

where, $(QR_{IN} - QR_{mar}) = GQR$ is government procurement and substitute in the equation (2.31).

$$\sum_{h=1}^{n} \Delta PS = \sum_{h=1}^{n} [GQR * (P_{GQR} - SFP_{IN})] \quad (2.32)$$

2.4.2.2 Changes in consumers' surplus

In the increased production year, extended subsidized price policy is not required as the retail market price is substantially lower (RPR_{IN}). If production decreases and become very deficit to fulfill demand due to the negative effect of climate, the deficit in supply causes consumer market price sharply to go up at RPR_D.

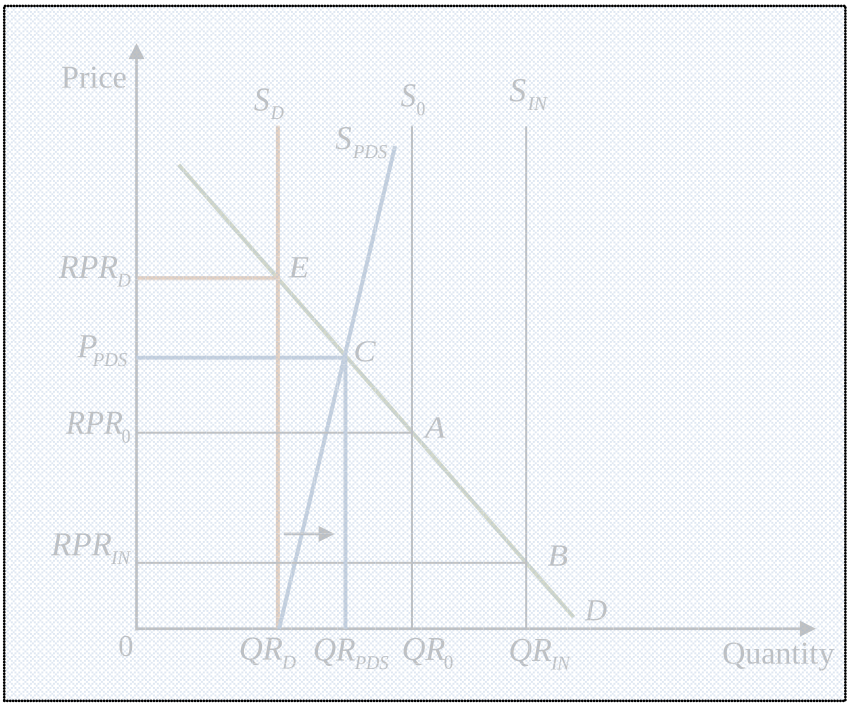

Figure 2.6 Consumer surpluses owing to the subsidy policy.

In response to higher market price, government releases stock to reduce the effect of price hikes and market supply would be the quantity indicated by QR_{PDS} and the supply curve is illustrated by S_{PDS} (Figure 2.6). As a result, consumers are benefited from this market price which is equivalent to $RPR_D P_{PDS} CE$. All individuals, who are strictly restricted to be price-takers, are willing to maximize utility. Change in consumer surplus can be written in the following form

$$\Delta CS = QR_{PDS} * (RPR_D - P_{PDS}) + \frac{1}{2}(QR_{PDS} - QR_D) * (RPR_D - P_{PDS}) \tag{2.33}$$

where, CS is the consumer surplus. A change in consumer surplus for all individuals ($h = 1, 2, ..., n$) is as follows:

$$W_{PDSt} = \sum_{h=1}^{n} \Delta CS$$

$$\sum_{h=1}^{n} \Delta CS = \sum_{h=1}^{n} [QR_{PDS} * (RPR_D - P_{PDS}) + \frac{1}{2}(QR_{PDS} - QR_D) * (RPR_D - P_{PDS})] \tag{2.34}$$

Where $(Q_{PDSt} - Q_{Dt}) = PDS_t$ is government distribution of rice and substituted in equation (2.34).

$$W_{PDSt} = \sum_{h=1}^{n} [QR_D * (RPR_D - P_{PDS}) + \frac{1}{2} PDS * (RPR_D - P_{PDS})] \quad (2.35)$$

Thus, the changes in social surplus due to the government intervention which is defined by the following expression:

$$W_{GQR} + W_{PDS} \quad (2.36)$$

2.4.3 Derivation of Procurement and distribution function

From the change in the surplus analysis, it appears that policy is necessary when market price (SFP_t) is not barely adequate to make a surplus by most of the marginal producers and when consumer price (RPR_t) is enormously peaked to go beyond the means of an individual consumer. In addition, the consumers are directed to lose significant access to purchase the necessary quantity of staple food in the market. To judge eerie consequent, the magnitude of price variation should be controlled through employing the government food policy. To implement a policy in favor of producers and consumers, public food policy has a physical constraint which must be reflected in analysis denoted as follows.

$$PBES_{t-1} + GQR_t + PDS_t + PBIMP_t \geq PBES_t$$

$$PBES_{t-1} \geq PBES_t - GQR_t - PBIMP_t + PDS_t \quad (2.37)$$

where, $PBES_{t-1}$ and $PBES_t$ are indicated by public beginning stock and ending stock respectively; GQR_t is indicated by the public procurement of rice; PDS_t is indicated by the public distribution of rice; and $PBIMP_t$ is indicated by public import of rice.

From the analysis of monthly paddy price in the market in Bangladesh, the representative price fluctuation is identified and shown in the figure 2.7 as follows. By simplifying a seasonal price fluctuation from figure 2.7, Figure 2.8 and 2.9 can be drawn to explain a comparison of changes in the market price with the government purchase price. Government continues to purchase paddy in *Aman* season from December through January. At initial point market when the market price is found to be lower than government purchases price, government purchase is adequately positive indicated by $GQR > 0$ and $GQR = 0$ would be when market price stay up abundantly higher than government purchase price. It is important to note that once government purchase price is declared and could not be changed to adjust in short period. The market price gradually tends to increase and peak at the end of the procurement terms in *Aman* season (Figure 2.9). In *Boro* season, Government continues to procure paddy from May through July. The market price of *Boro* paddy tends to drop over the terms of *Boro* harvest even though the initial price is relatively higher than government purchase price. Farmers compare the government purchase price with a present market price (Figure 2.9). As a result, P_{GQRt} / SFP_{INt} or $(P_{GQRt} - SFP_{INt})$ is more realistic to use in the model other than individual price used to be independent factors. Procurement is zero when the market price goes up relative to the procurement price. Recent days, the government usually gives more emphasis to purchase paddy in *Boro* season when a huge quantity of rice could be produced than other season. The more comprehensive and reasonable modeling should be next challenge to research.

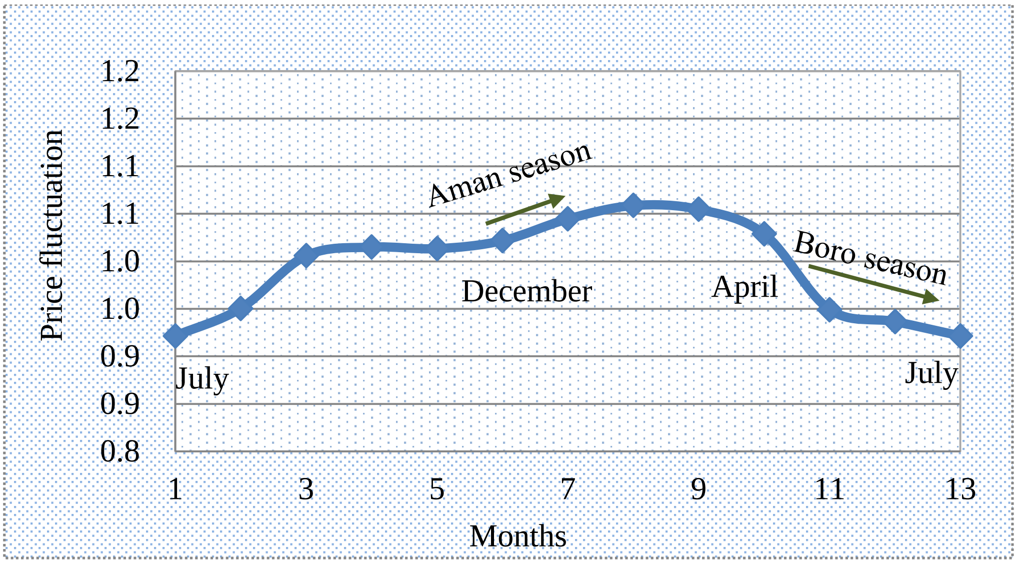

Figure 2.7 Representative monthly price fluctuations in Bangladesh

Source: Author calculation from Food Planning and Monitoring Unit, Ministry of Food and Disaster Management, Bangladesh, 2009

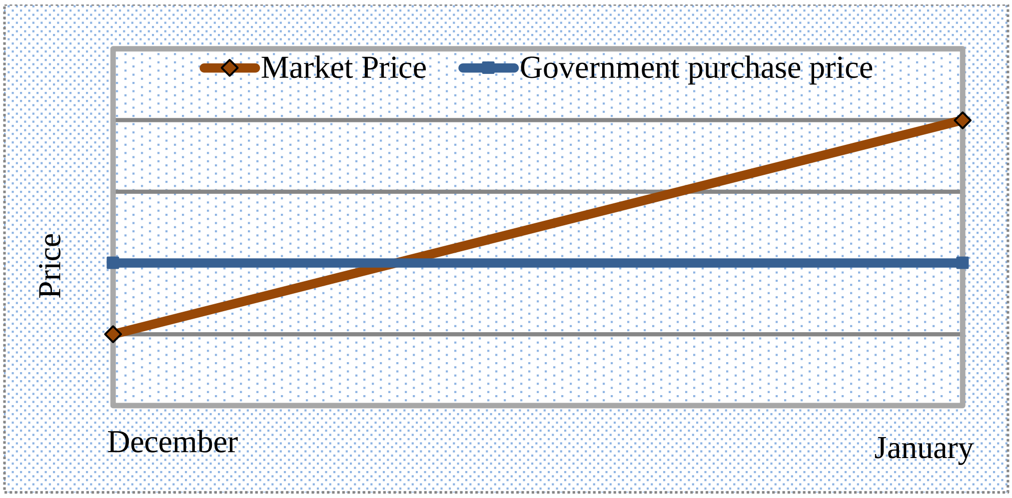

Figure 2.8 Price change between market price and support price in *Aman* season

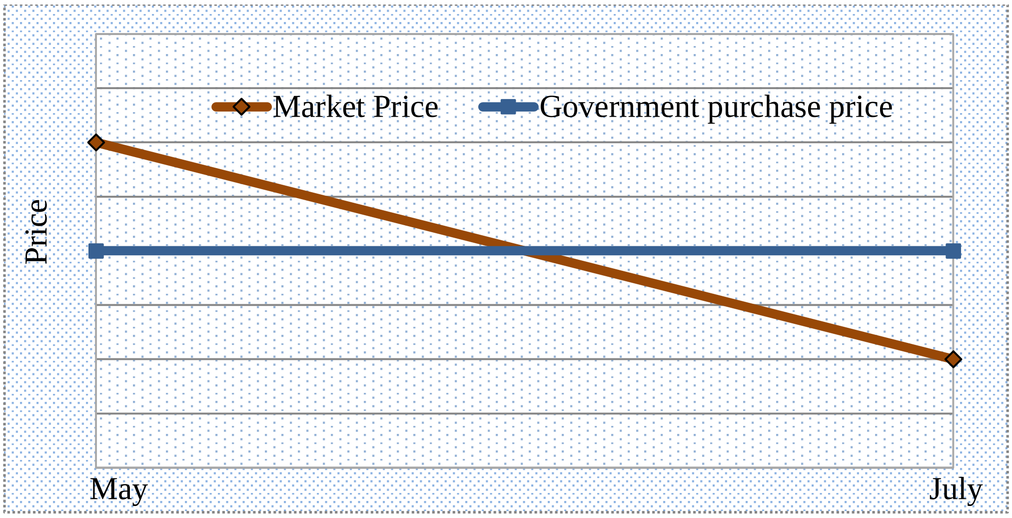

Figure 2.9 Price change between market price and support price in *Boro* season

It is also assumed that quantity demand of procurement can also be affected by the quantity of production and the level of public beginning stock ($PBES_{t-1}$). The higher beginning stock is considered as physical constraints to lower procurement activities and higher production (QR_t) stimulate higher procurement activities.

In setting procurement function, the government purchase price (P_{GQR}), the farm gate price (SFP_t), the quantity of production (QR_t) and the physical constraint ($PBES_{t-1}$) are principally possible explanatory variables which should be included. Procurement function is constructed as follows:

$$GQR_t = f_{GQRT}[(P_{GQRt} - SFP_{INt}), QR_t, PBES_{t-1}] \qquad (2.38)$$

The difference between government purchase price and farm gate price $(P_{GQRt} - SFP_{INt})$, production level (QR_t), and physical constraint ($PBES_{t-1}$) are used for estimation of the actual function of procurement.

The quantity of public distribution is affected by changes in retail price as well as the physical constraint. Quantity demand for the public distribution by households is affected by the extended subsidized price. In setting public distribution function, changes in consumers price ($(RPR_t - RPR_{t-1}) = \Delta RPR$) , extended subsidized price (P_{PDS}) and the physical constraints are also essential explanatory variables.

Similarly, public distribution function can be formulated and this is stated in the following mathematical expression

$$PDS_t = f_{PDSt}(P_{PDSt}, \Delta RPR, PBES_{t-1}) \qquad (2.39)$$

where, change in retail price ΔRPR; subsidized price P_{PDS} , and physical constraint $PBES_{t-1}$ are for estimation of the actual function of public distribution.

CHAPTER–III

METHODOLOGY AND ESTIMATION PROCEDURES

3.1 Algorithm for Solving Demand and Supply System

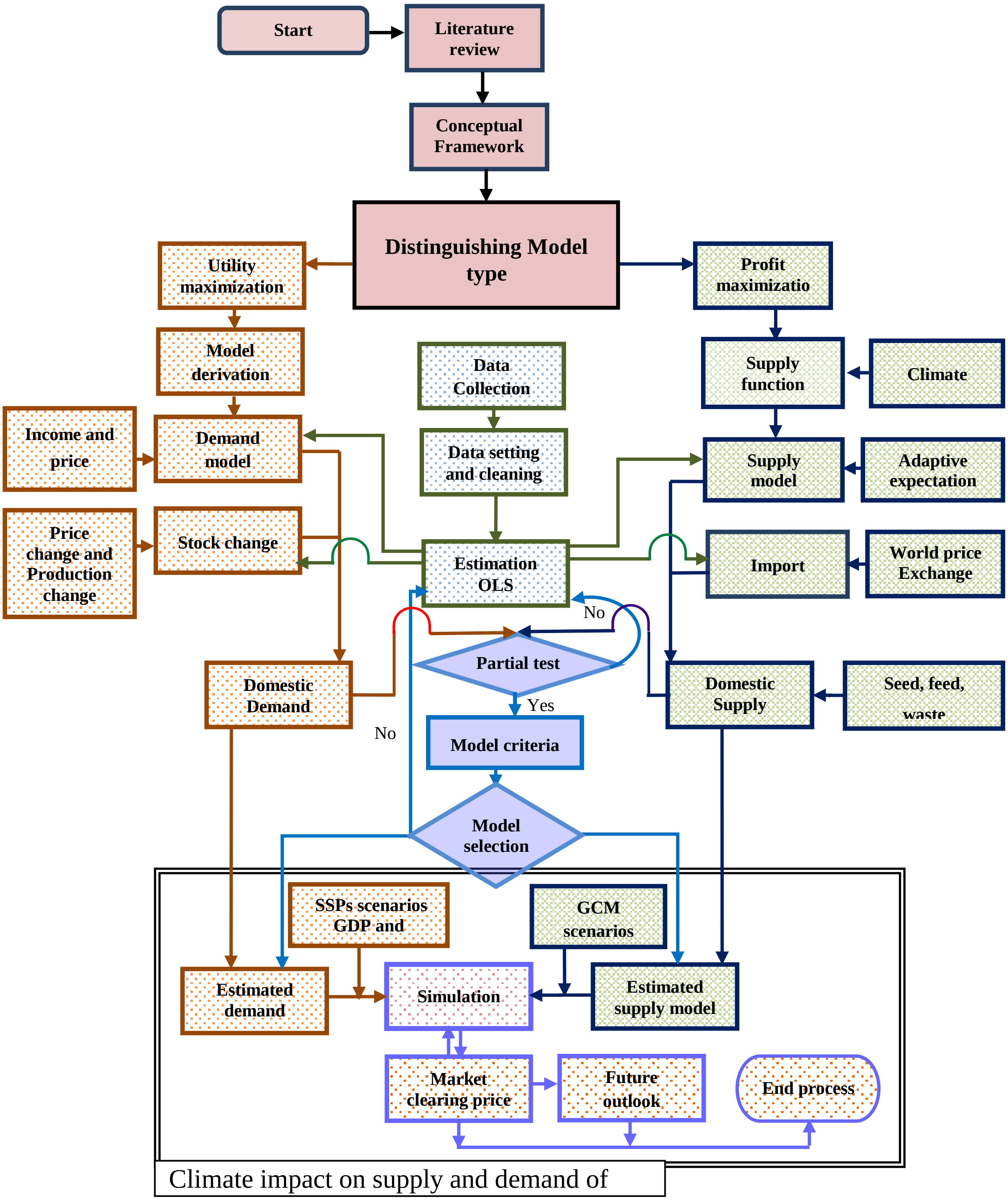

Figure 3.1 Diagram for demand and supply model system

The algorithm of modeling system displayed a continuous flow of derivation of a theoretical model and deliberately proceeded to solve empirical supply and demand system. To follow the repeated procedures, parameters of supply and demand systems were estimated by using Statistical Analysis System (SAS) programming language. In the process, a solution of the complicated system was simulated and finally, market equilibrium was achieved through Gauss-Seidel approach. At the final step, the procedures also executed an equilibrator to find the expected point of convergence that would be secured at domestic market clearing price through price linkage function (PL) in Microsoft office Excel which would further be described in the convergence mechanism. The market–clearing condition could be presented as below:

$$NSR_t - DDR_t * POP_t = 0 \qquad (3.1)$$

where, NSR_t was the net supply in the market, DDR_t was per capita domestic demand, and POP_t was the population.

The retail price of rice was a driving wheel of market clearing mechanism. When climate scenarios combined with scenarios on population and income were incorporated in the system, the retail price would be established in the market mechanism when supply and demand is converged. Each adjustment was passed back to the effective producer price and retail prices through the upstream price transmission (price linkage indicated by equation (3.12)). Changes in market prices successively influenced the interaction of supply and demand and an iteration of price adjustment could repeatedly be conducted in the following procedures.

3.2 Convergence Mechanism (Equilibrator)

Adjusted value (ADV_t) = $(PSR_t - DDR_t) \times (-DF)$ (3.2)

where, $PSR_t = NSR_t / POP_t$ could be defined as per capita supply and DF was dumping factor which could be measured as a constant number.

RPR_t went up when PSR_t increased and DDR_t decreased.

where RPR_t was called as an ending price or retail price

$PSR_t > DDR_t$ when ADV_t became negative and RPR_t decreased

$PSR_t < DDR_t$ when ADV_t became positives and RPR_t went up

The iteration process was terminated when $ADV_t = 0$.

3.3 Variable of Rice Sectors and Their Interrelationship

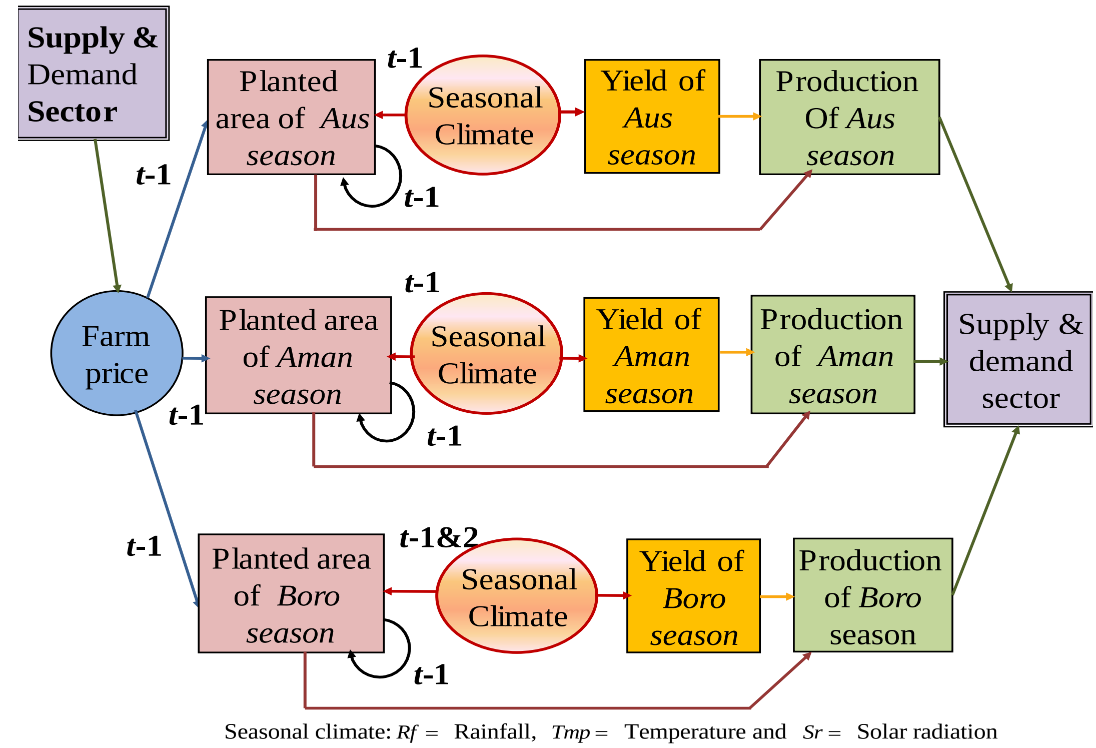

Figure 3.2 Seasonal rice production sectors in Bangladesh

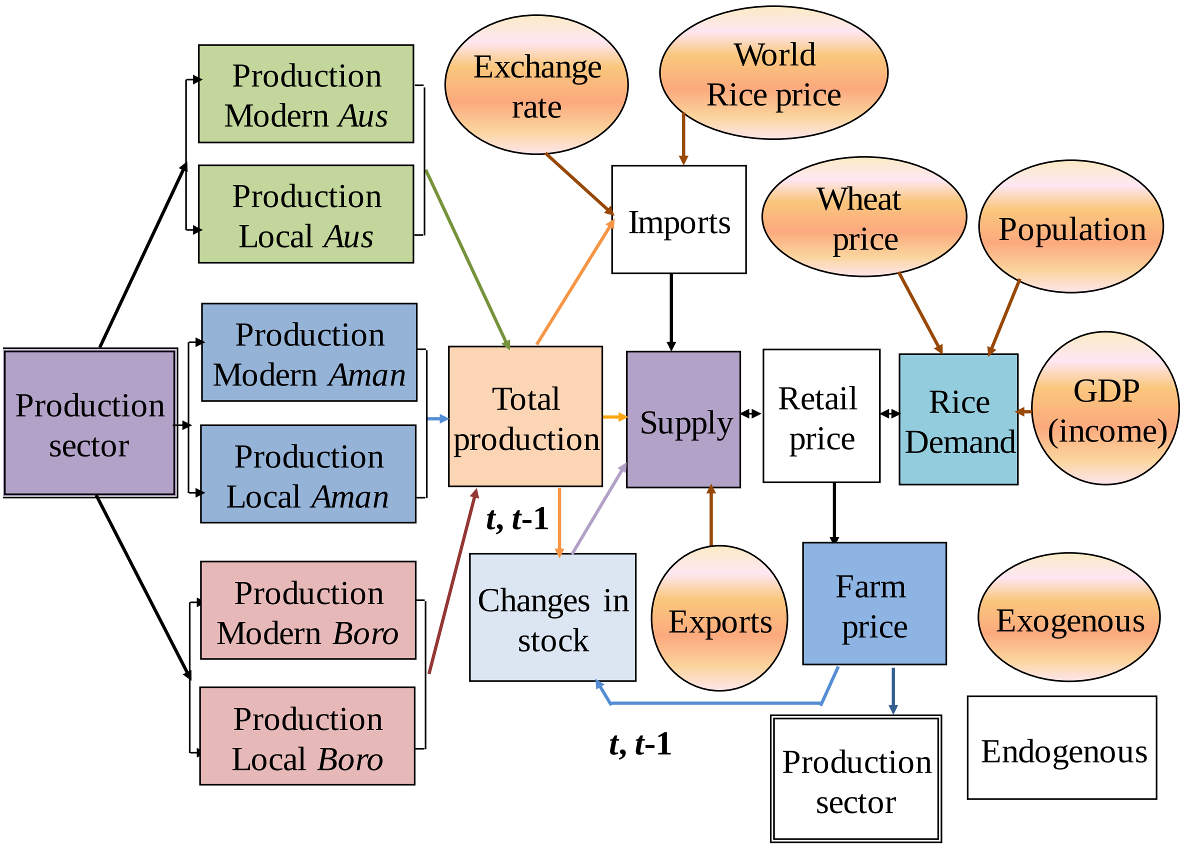

Figure 3.3 Supply and demand of rice sector in Bangladesh

Figure 3.2 represented the schematic model structure for seasonal rice production sector and further exhibited effect of climate variables on the production. The production sector had been designed following the three rice–growing seasons having the local names as well according to harvest period, was explained in an earlier section. The designated diagram of production sectors had been viewed three different lines of flow–which could be represented by *Aus*, *Aman* and *Boro* in figure 3.2. In model flows that could once more be decomposed just to understand based on what were called rice varieties (MV and Local). It appeared in the diagram that climate variables were integrated to simultaneously affect the determination of yield as exogenous in present period and have also an effect on the allocation of the planted areas with lagged period. Production sector had been ended up with total production that was computed from estimated area and yield. Afterward, gross productions in all seasons were moved to enter into the supply and demand sectors. It was important to point out that farm price what they experienced with one year back, which was determined in the supply and demand sector, affected the farmers' decision on allocation of planted rice area as exhibited in the figure3.2. Supply and demand sector in Bangladesh was systematically illustrated in the followed figure 3.3.The market supply, which had been counted up under net supply, was obtained from gross production, stock change, import, indirect demand (seed, feed, process and other uses), and export demand. As a counterpart of supply, quantity demand could be explained by market price, population, and income. In addition, farm price was actually fixed up from the upstream transition of the retail price in the market and that should have been cleared up to be equilibrium through interactive forces of supply and demand sectors.

3.3.1 Areas and yield

The supply was basically formulated in two steps: First step determined acreage allocation based on farmers' price expectation and in the following step, the yield was determined in yield response function. Seasonal area (AR_{iv}) was multiplied with yield (YR_{iv}) to get the annual total rice production (Figure 3.3). Rice cultivations were being practiced across three seasons which were distinguished as *Aus* season from March to late July, *Aman* from May to late–December, and *Boro* from November to late–May. Most of the farmers engaged in growing two kinds of cultivars which could be categorized into MVs and Local. Even though total rice acreage had been almost flat with nearly 10 million, there had been substantial dispersion across area coverage and yield performance of different varieties in the main growing seasons. A separate model was developed based on season and varieties that could cover the behavior of seasonal yield variations and the difference in seasonal areas and that could also cover the magnitudes of inter–seasonal dispersion.

3.3.2 Market price of rice and exchange rate

There were two different price sets which had been dealt in the domestic market in Bangladesh. Both annual prices of rice that were defined as producer and retail price displayed a degree of variability and a steady upward trend over the decades. Retail rice price was substantially higher compared to producer price as the marketing cost from producers 'points onward, sale taxes and value addition continued to include (Figure 3.4).

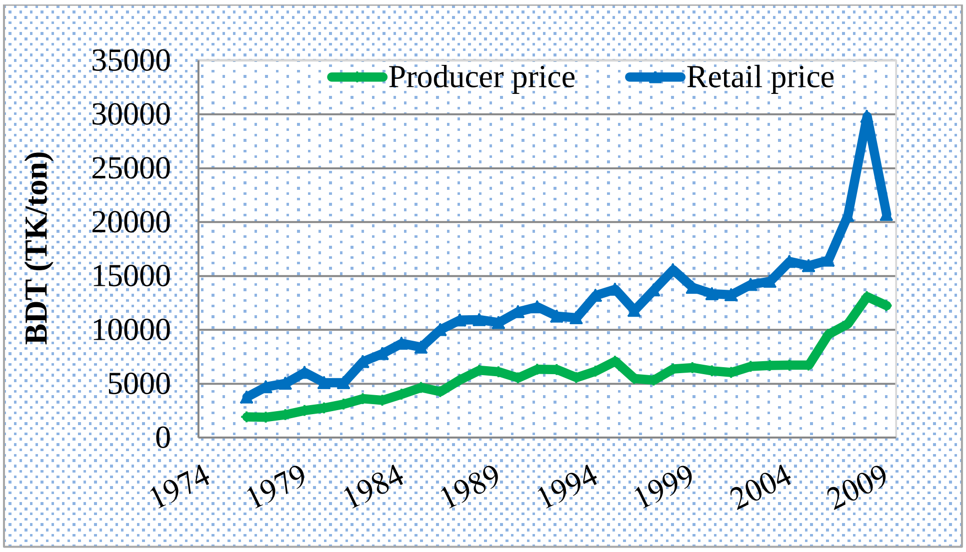

Figure 3.4 Producer price and retail price of rice in 1974–2009.
Source: Author's plotting

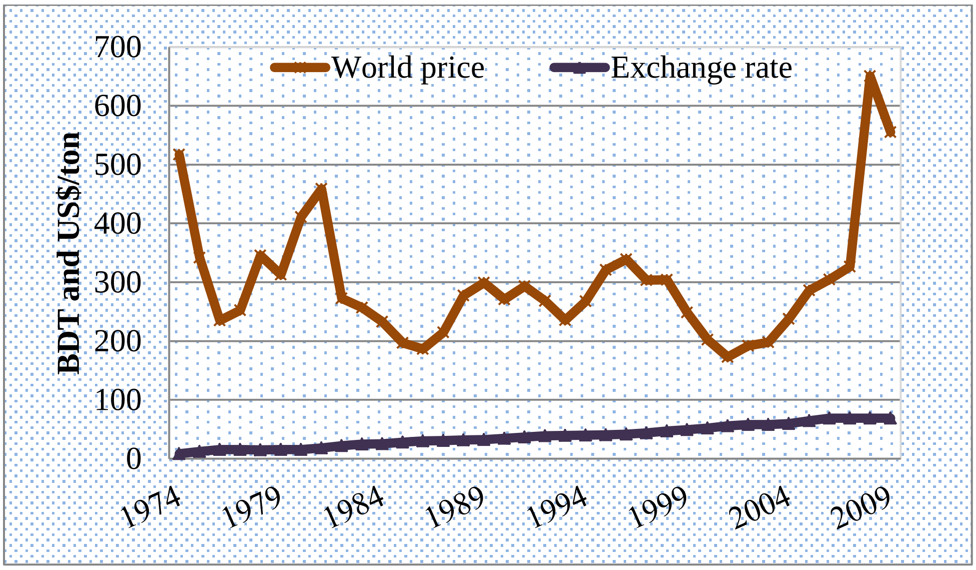

Figure 3.5 World rice price and exchange rate against the dollar in 1974–2009.
Source: Author's plotting

There was no doubt to assume that price movement from retail price to producer price in Bangladesh was found to be the upstream transmission. World prices of rice and exchange rate of dollar affected the decision of quantity import in Bangladesh which later influenced on government food policy and also served to bring balance to the domestic food market in relation to world food market. Figure 3.5exhibited an irregular trend of the world price of rice and a steady increasing trend in the exchange rate.

3.3.3 Stock change

The stock of rice played an important role in food distribution in the domestic food system. The stock change was computed from the difference between the Beginning stocks and Ending stocks of rice in Bangladesh which could be done by the public as well as private sectors. Stock change became negative when market price exists to be higher. The stock change usually became positive when market price stayed being lower than the price that the stock holders expected. Most of the statistical data source publishes stock variation other than the stock itself. The stock change was considered as domestic demand sector. Figure 3.6 on stock change over the period exhibited a prior expectation.

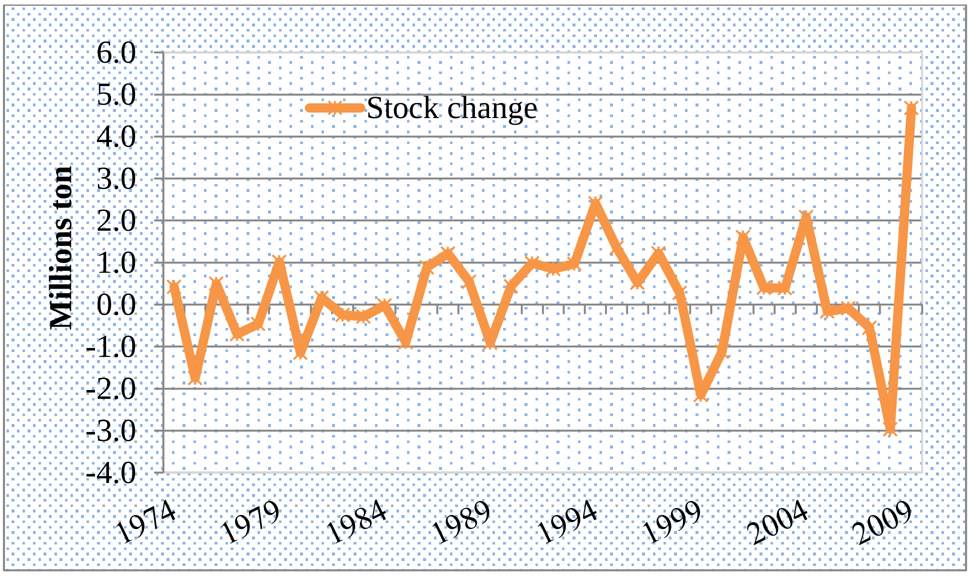

Figure 3.6 Picture of rice stock change in 1974–2009.
Source: Author's plotting

3.3.4 Population

National population statistics were adopted to investigate the impact of population growth on supply and demand sector. Figure 3.7 showed the increasing growth of national population in Bangladesh. The trend of the population was reflected as one of the major indicators in a national economic structure that must have been considered in order to devise a policy instrument.

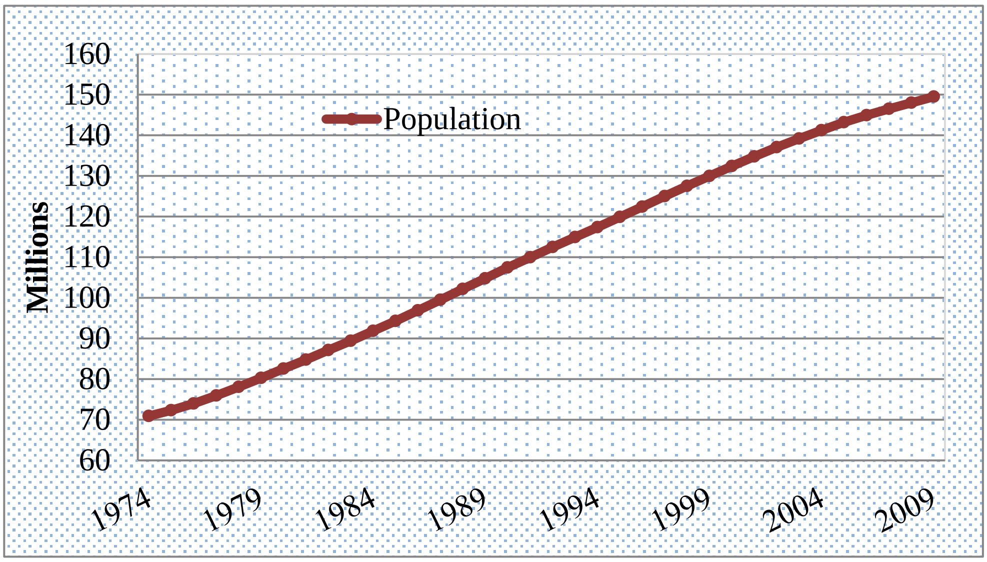

Figure 3.7 National population statistics in Bangladesh in 1974–2009.
Source: Author's plotting

Per capita income from gross domestic products and per capita rice demand were computed using population and the possible influence of population growth on demand outlook could be done incorporating population scenarios in the complete structure of simulation.

3.3.5 Rice demand

To authenticate per capita demand norm and estimate food requirement, national demand was computed from national food requirement and national population statistics. Domestic demand for rice, that could be regressed with the population, retail price, per capita income and other inducing factors, was balanced with the counterpart delineated as market supply through market equilibrium condition.

3.3.6 Gross domestic product (GDP)

Gross domestic product (GDP) at constant market prices could be expressed in term of income, production, and expenditure. In expenditure term, GDP was a sum valuation of expenditure on final goods and services minus imports, final consumption expenditures, gross capital formation, and exports subtracted by imports. "Gross" indicated that the depreciation of machinery, buildings and other capital products used in production was not taken into account in the process of valuation. "Domestic" meant that products were only produced and consumed in the demarcated economic territory of the country. The products denoted final goods and services, which were purchased, imputed or otherwise, final consumption of households, non-profit institutions serving households and government,

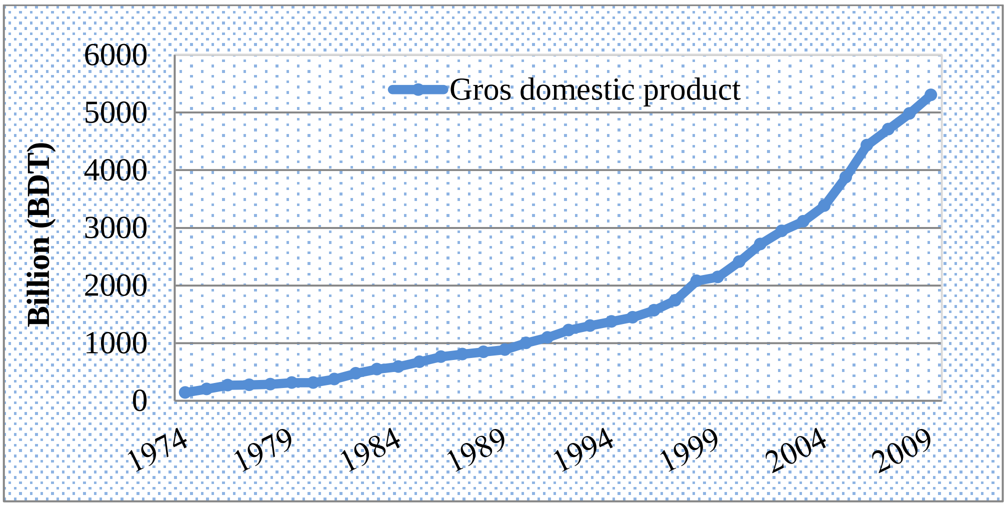

Figure 3.8 Gross domestic products in Bangladesh in 1974–2009.
Source: Author's plotting

fixed assets, and trade balance (Organization for Economic Co-operation and Development, 2017). Figure 3.8 exhibited the upward increasing trend of GDP in Bangladesh. The straight upward trend of GDP growth could be regarded as the appealing strength of the economy and improving the living standard through domestic production and consumption.

3.3.7 Deflator of gross domestic product (GDPD)

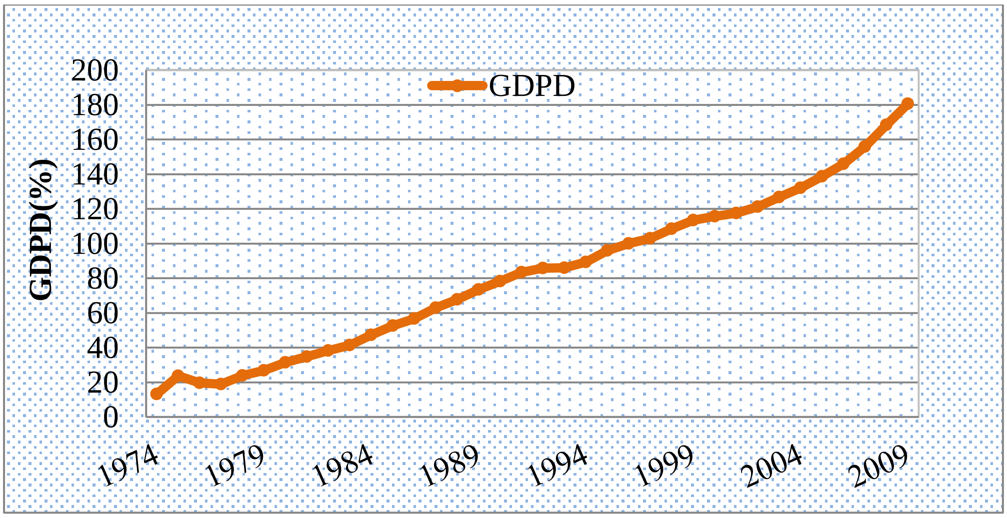

Figure 3.9 GDP deflator of Bangladesh economy in 1974–2009.
Source: Author's plotting

GDP deflator was defined as a ratio of GDP in the current year to GDP in the constant currency in the base year. Increasing trend of the GDP deflator indicated the expansion of GDP and increasing trend in monetary inflation (Figure 3.9). Due to the limited datasets of consumer as well as producer price index, the present study utilized GDP deflator that could realize time series market price and income.

3.3.8 Rice import in Bangladesh

Encountering difficulty and uncertainty in import and international trade along with the famine in the past, Bangladesh had adopted self–sufficiency policy for food and as such utilized the green revolution technologies. Consequently, higher gains in rice production enabled Bangladesh enough to reduce its dependency on import and food aid.

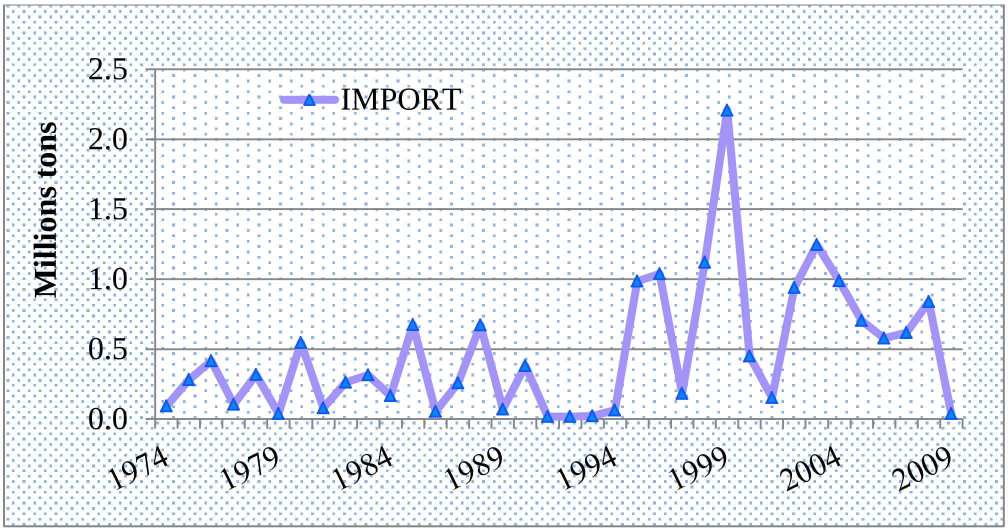

Figure 3.10 Import of rice in Bangladesh economy in 1974–2009.
Source: Author's plotting from

Even though, Bangladesh had remarkable success in rice sufficiency among the major rice producing countries, figures 3.10 was alluded to be constant imports of rice, would possibly be major reason that domestic production had been inadequate to meet the emergency shortfall and control unpredicted price hikes. To avoid uncertainty, Bangladesh continued to maintain a long term import contract in order to overcome the marginal shortage caused by erratic climatic events. Historically, import had constituted barely a small share of national rice supplies. In addition, import was actually regarded to have a somewhat contribution to reducing price drifting (Dorosh, 2009; Kumar *et al.*, 2012; Talukder, 2005; Dorosh and Rashid, 2012).

3.3.9 Climate variables

The earlier chapter focused thoroughly on the seasonal pattern of rice cultivations in Bangladesh. The rice-growing seasons in Bangladesh were defined as *Aus* season from March through late July, *Aman* from May through late–December, and *Boro* from November through late–May. Monthly average climate variables that were categorized according to seasonal periods of rice cultivation are incorporated in the seasonal yield function and area function. Generally, weather of Bangladesh was very hot and humid. The annual average precipitation is very often more than 1,500 mm/year and the hottest month April with the temperature between 33°-36°C in summer. The coolest month is January with an average temperature of 26° C in winter (National Encyclopedia of Bangladesh, 2017).This study utilized the monthly average climate variables in order to figure out the effect of climate variation on the rice production. In addition, the model analysis would give a detail discussion on climate variables and discussed the magnitude of climate effect on crop yield in the chapter of result and interpretation.

3.3.10 Other variables

Some other variables included indirect demand viz. seed, feed, process and other usage, and also export. Export demand was very small because there was not yet created well-organized of bilateral market linkage as well as a lack of premium grade of rice. Therefore, the export demand for Bangladesh rice was almost under developed in the world market. Seed, feed, process, and other usage were domestic demands which must be incorporated in order to determine net supply in the market. These variables, which had been intermingled in the relationship, would have been shown in supply and demand sector.

3.4 Empirical Model of Supply and Demand

To generate outlook on the variation of supply and market price of rice under climate change, rice yield, acreage, stock change, and demand functions were developed. Furuya and Meyer (2008) and Furuya *et al*. (2010) used a supply and demand system approach to determine market supply and market prices in Cambodia, Laos, and Thailand. The basic structure of their model had been followed to construct the model system in this piece of research. The variables used for supply estimation were production, imports, stock change, and indirect demand. Yield and acreage were combined to obtain production. The variables used for demand estimation were population, Gross Domestic Product (GDP), and market prices. The variables such as a change in the retail price of rice and production were incorporated in the stock change function while import function includes world price and current year production which was derived from conventional postulation. Considering the climate as one of the major determinants, yield function was constructed incorporating climatic variables (rainfall, temperature, and solar radiation) and time trends, as used for technological progress (improved cultivars, all kind of machinery and fertilizers). The area function was constructed based on a joint assumption of partial adjustment and adaptive expectations (Nerlove, 1958) to interpret farmers' responses to supply prices and climate factors. A separate yield and acreage functions were developed to capture inter-seasonal dispersion of yields and areas because rice yields and areas differ across varieties and seasons (Kumar *et al.*, 2012).

Monthly average climate variables were categorized according to seasonal periods which were repeatedly used in the estimation of seasonal yield and acreage model. The inclusion of dummy variables in the area and other functions facilitates the explanatory power of model and they are regarded as climate related extreme events, such as cyclone, flood, and drought year. Variables in supply and demand system were categorized into two groups which were endogenous in one side (squares in Figure 3.2 and 3.3) and exogenous to another side (circles in Figure 3.2 and 3.3). The estimated functions including endogenous and predetermined exogenous variables were detailed as follows.

3.4.1 Yield functions

$$YR_{ivt} = \alpha_{ivYR} + b_{ivYR1}T + b_{ivYR2}Z_{imt} \tag{3.3}$$

where, YR_{ivt} was the paddy yield of varieties, v = 1 and 2 (modern and local) in seasons i = 1, 2, and 3 (*Aus*, *Aman*, and*Boro*). T was the time trend that was used as a proxy for technical change, irrigation and machinery facilities and Z_{im} denoted seasonal climatic variables which were specified by temperature (*Tmp*), rainfall (*Rf*), and solar radiation (*Sr*) in months (m) in year t. a_{ivYR}, $b_{ivYR1}$and b_{ivYR2} were parameters estimated as statistically significant.

3.4.2 Area functions

$$AR_{ivt} = a_{ivAR} + b_{ivAR1}AR_{iv(t-1)} + b_{ivAR2}SFP_{t-1} / (GDPD_{t-1} / 100) + b_{ivAR3}Rf_{im(t-1)} \tag{3.4}$$

where, AR_{ivt} was the harvested area and $AR_{iv(t-1)}$ was lagged area. SFP_{t-1} was the lagged farm price deflated by lagged GDP deflator $GDPD_{t-1}$ and $Rf_{im(t-1)}$ was the lagged of seasonal rainfall in months (m). a_{ivAR}, b_{ivAR1}, b_{ivAR2} and b_{ivAR3} were estimated parameters.

3.4.3 Paddy and milled rice identity

To obtain total production of milled rice, area and yield were combined and multiplied by a standard ratio as follows:

$$QPR_{ivt} = \sum_{i,v} AR_t * YR_t \tag{3.5}$$

$$QR_{ivt} = 0.67 * \sum_{i,v} QPR_t \quad (3.6)$$

where, total production was QPR_{ivt} and milled rice (QR_{ivt}) was determined by a standard conversion ratio of 0.67.

3.4.4 Import function

The import function could be constructed as follows:

$$IMPR_t = a_{IMPR} + b_{IMPR1} \sum_{i,v} QR_t + b_{IMPR2} [(WPR_t * EXR_t) / (GDPD_t / 100)] \\ /[RPR_t / (GDPD_t / 100)] \quad (3.7)$$

where, $IMPR_t$ was the quantity of import in time *t*, QR_{ivt} was domestic production and WPR_t was world price (Thailand 5% broken) over retail price (RPR_t) normalized by the GDP deflator $GDPD_t$. EXR_t was the exchange rate (BDT/US$). a_{IMPR}, b_{IMPR1}, and b_{IMPR2} were estimated parameters. As an importer, Bangladesh did not participate very much in the world rice trade and, in fact, did not have an influential control on the world rice market. Inversely the world market price and quantity of domestic production affected the import decision and domestic supply in Bangladesh. Therefore, supply and demand of Bangladesh does indeed not affect world price of rice (WPR), which was used as the exogenous factor in the import model.

3.4.5 Stock change function

$$STC_t = a_{STC} + b_{STC1} (\sum_{i,v} QR_t - \sum_{i,v} QR_{t-1} + b_{STC2} \\ [RPR_t / (GDPD_t / 100) - RPR_{(t-1)} / (GDPD_{(t-1)} / 100)] \quad (3.8)$$

The stock change could be defined by ending stock minus beginning stock. The stock change (STC_t) function was influenced by variation between present production (QR_{ivt}) and lagged production ($QR_{iv(t-1)}$) and between present realized retail price (RPR_t) and lagged price (RPR_{t-1}). a_{STC},b_{STC1}, and b_{STC2} were estimated parameters.

3.4.6 Net supply identity

$$NSR_t = \sum_{i,v} QR_t + IMPR_t - STC_t - IDDR_t (EXPR_t, ROC_t, SEED_t, FEED_t, OU_t) \quad (3.9)$$

where NSR_t was net supply determined by adding imports ($IMPR_t$) and subtracting change in stock (STC_t) as well as $IDDR_t$ was indirect demand (export $EXPR_t$., process $PROC_t$, seed $SEED_t$, feed $FEED_t$, and other OU_t).

3.4.7 Demand function

The demand function was developed using utility theory, as follows.

$$DDR_t = a_{QD} + b_{QD1}RPR_t / (GDPD_t / 100) + b_{QD2}RPW_t / (GDPD_t / 100)$$
$$+ b_{QD3}[(GDP_t / POP_t) / (GDPD_t / 100)] \quad (3.10)$$

where, per capita demand (DDR_t) was influenced by retail price (RPR_t), the wheat retail price (RPW_t), which was a major substitute for rice, and income (GDP_t/POP_t) and POP_t was population. a_{QDR}, b_{QDR1}, b_{QDR2}, and b_{QDR3} were estimated parameters. Moreover, the projected GDP, common scenarios to all researchers, was estimated by the SSPs of IIASA and. On the other hand, the share of rice in GDP was not so larger such as 5% in 2014 (BBS, 2014), thus per capita GDP was incorporated as exogenous scenarios in the demand model.

3.4.8 Market equilibrium of supply and demand

$$NSR_t - DDR_t * POP_t = 0 \quad (3.11)$$

3.4.9 Price linkage function

The market price of rice in Bangladesh was an upstream transmission.

$$SFP_t = a_{FP} + b_{FP}RPR_t \quad (3.12)$$

FP_t was the farm gate price, which was influenced enormously by the retail price (RPR_t). a_{FP} and b_{FP} were statistically significant parameters to be estimated.

All variables were clearly specified as endogenous and exogenous. Endogenous variables were production (QR_{ivt}) obtained from the area (AR_{ivt}) and yield (YR_{ivt}), imports ($IMPR_t$), stock change (STC_t), net supply (NSR_t) per capita demand (DDR_t), farm price (SFP_t), and retail price (RPR_t). The endogenous variables were determined in the model system.

Predetermined or exogenous variables, which were determined outside the model system, were denoted by time trend (T), seasonal temperature Tmp_{im}, rainfall Rf_{im}, solar radiation Sr_{im}, Gross Domestic Product (GDP_t), indirect demand (processed $PROC_t$, seed $SEED_t$, feed $FEED_t$, and other OU_t), exports $EXPR_t$, world price of rice (WPR_t) and population POP_t. The inclusion of necessary dummy variables in yields and areas including all specified system functions facilitated explanatory power of model regarding external factors and climate related extreme events, such as policy measure for rice price, cyclone, flood, and drought year. Moreover, dummy variables could be a remedial measure to fix those influential observations and assisted estimation progress to generate a good fit model being consistent with the actual data.

3.5 Empirical Policy Model Framework

This section was a hub of concerns with the model structure for a counter measure to investigate the reduction of price variation which could likely be induced by the climate variation. Figure 3.11 exhibited the further decomposition of the domestic small open economy where public food policy was the most crucial engine that influenced the market movement. Moreover, rice market was once more segregated into public operation and private participation in the supply and demand sector. The public sector dealt with three important components of food policy that influenced the market price such as procurement, distribution, and import. Public stock was essentially being built up from procurement and import that would be continued to carry. The necessary quantity of stock was decided to release in the market when the shortage of market supply pushed the price to escalate up. On the other hand, private participation in the supply and demand sector was dominated by a speculation of market price to make a profit. Private sector began to import rice since trade liberalization in the era of 1990s and since then, contributed to improve higher supply gap and meet the emergency market demand that would more likely happen during the time of food shortage. The private traders commonly persisted to carry the quantity of grain stock based on a signal of market price and start off releasing the stocks when the market price was seemed to realize the expected margin. To join up two market forces, both the actors in the market played a vital role to keep the market going to be smooth functioning. Therefore, policies model had been devised to incorporate into the market mechanism that dealt mostly with the public activities and thereby reducing the variation of market price which had been projected to be induced by the change of climate variables.

3.5.1 Procurement function

Demand for government procurement function was given as follows:

$$GQR_t = \alpha_{itGQR} + b_{itGQR1}\sum_{i,v} QR_t + b_{itGQR2}[(P_{GQRit}/(GDPD_t/100) - SFP_{it}/(GDPD_t/100)] + b_{itGQR3}PBES_{t-1} \quad (3.13)$$

where, GQR_{it} was the annual public procurement and P_{GQRt} was support price. $PBES_{t-1}$ was beginning stock which was considered as physical constraints. $\alpha_{itGQR}, b_{itGQR2}$ and b_{itGQR3} were parameters related to the procurement function. The government usually procured paddy from market and farmers to influence market price and assured farm price to farmers and at same breath, did an important attempt to build public stock through buying the necessary amount of paddy (Dorosh and Rashid, 2002).

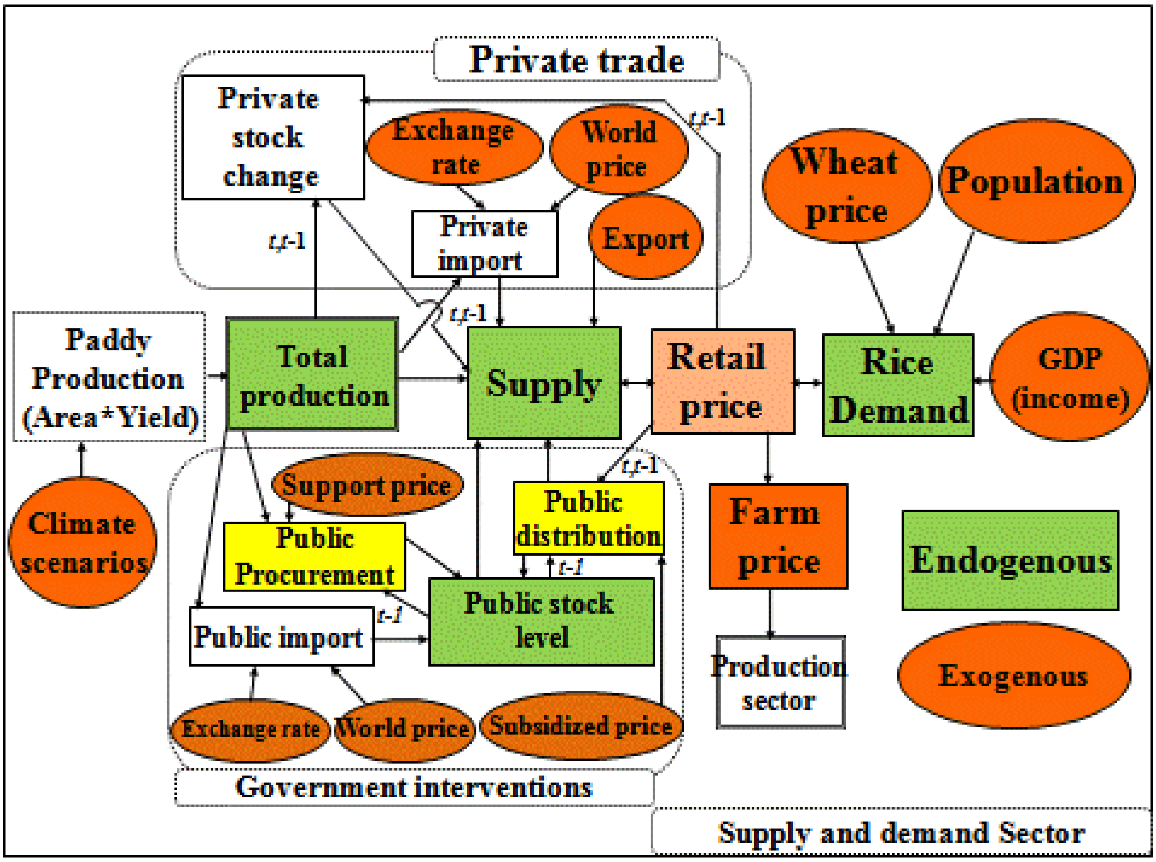

Figure 3.11 Supply and demand sector of rice in Bangladesh with public operation

3.5.2 Import function

Both public and private import function were mathematically specified as follows:

3.5.2.1 Public import function

$$PBIMP_t = \alpha_{PBIMP} + b_{PBIMP1}(\Sigma_{i,v} QR_t - \Sigma_{i,v} QR_{t-1}$$
$$+ b_{PBIMP2}[((WPR_t * EXR_t)/(GDPD_t/100))/(RPR_t/(GDPD_t/100))] \quad (3.14)$$

3.5.2.2 Private import function

$$PVIMP_t = \alpha_{PVIMP} + b_{PVIMP1}(\Sigma_{i,v} QR_t - \Sigma_{i,v} QR_{t-1})$$
$$+ b_{PVIMP2}[(WPR_t * EXR_t)/(GDPD_t/100)]/[RPR_t/(GDPD_t/100)] \quad (3.15)$$

where, $PBIMP_t$ and $PVIMP_t$ were government and private import, respectively. $QR_{ivt} - QR_{iv(t-1)}$ was the change in production. WPR_t and EXR_t were world rice price and exchange rate, respectively. RPR_t was the retail price of rice. α_{PBIMP}, b_{PBIMP1}, b_{PBIMP2}, α_{PVIMP}, b_{PVIMP1} and b_{PVIMP2} were parameters related to import. Both government and private traders had played a vital role in parallel line through import since trade liberalization in 1990s and met emergency shortage to reduce the effect of unpredicted price hikes. Therefore, allowing participation of private import was a seal of stable market price which, in turn, made a right balance between supply and demand (Dorosh, 2009; Dorosh and Shahabuddin, 2002).

3.5.3 Public distribution function

Public distribution was stated as follows:

$$PDS_t = \alpha_{PDS} + b_{PDS1}[RPR_t / (GDPD_t / 100) - RPR_{t-1} / (GDPD_{t-1} / 100)] \\ + b_{PDS2} P_{PDSt} + b_{PDS3} PBES_{t-1} \quad (3.16)$$

where, PDS_t and $PDPR_t$ were the government distribution and subsidized price, respectively. α_{PDS} , b_{PDS1}, b_{PDS2} ,and b_{PDS3} were parameters related to the distribution function.The public stock was decided to release when the market price was found to go up substantially beyond what might exist in the previous time. Distribution was carried out at subsidized price that was usually decided by government and was subject to physical constraint.

3.5.4 Public stock identity

$$PBES_t = PBES_{t-1} + GQR_t + PBIMP_t - PDS_t \quad (3.17)$$

where $PBES_t$ was the government ending stock.

3.5.5 Private stock change function

Private stock change function was expressed as follows:

$$PVSTC_t = \alpha_{PVSTC} + b_{PVSTC1}(\sum_{i,v} QR_t - \sum_{i,v} QR_{t-1}) \\ + b_{PVSTC2}[RPR_t / (GDPD_t / 100) - RPR_{t-1} / (GDPD_{t-1} / 100)] \quad (3.18)$$

where, $PVSTC_t$ was private stock, α_{PVSTC} , b_{PVSTC1} and b_{PVSTC2} were parameters. Price expectation of private trader was a major factor in stock carries (Timmer, 2009; Dorosh *et al*., 2012). Therefore, Inter–temporal arbitrage in the price variation and changes in domestic production influenced private stock change.

3.5.6 Net supply identity of rice

$$NSR_t = \sum_{i,v} QR_t - GQR_{it} + PDS_t + PBIMP_t + PVIMP_t - PVTC_t \\ - IDDR_t(EXPR_t, ROC_t, SEED_t, FEED_t, OU_t) \quad (3.19)$$

where, NSR_t was the net market supply of rice and indirect demands $IDDR_t$ were export EX_Pt, seed SD_t, processed $PROC_t$ and other uses OU_t.

3.5.7 Fiscal cost determination

Fiscal cost incorporated expenses of procurement, import, and value of food distribution within a fiscal year as follows:

$$FC_t = GQR_t * P_{GQRt} + PBIMP_t * (WPR_t * EXR_t) - PDS_t * P_{PDST} \quad (3.20)$$

where, FC_t was the fiscal cost.

3.6 Data Sources and Collection

Historical areas and yields were gathered from the Bangladesh Bureau of Statistics (BBS, 2014). Additional data related to farm and retail prices were collected from world rice statistics. Exports, imports, and stock change of rice were collected from the Food and Agriculture Organization (FAO) as well as GDP and GDP deflator were from World Data Bank (World Bank (a)). Public procurement, distribution and corresponding prices data were adopted from Food Planning and Monitoring Unit (FPMU), Food Database, Ministry of Food and Disaster Management, Bangladesh. Household expenditures on food and non–food consumption were collected from Household Income and Expenditure Survey, 2010 in Bangladesh. Then, historical temperature, rainfall, and solar radiation were collected from the Data Distribution Centre of the IPCC. Forecast climatic variables under Representative Concentration Pathways (RCPs) over the period 2010 to 2030, which were used in this study, is developed by Model for Interdisciplinary Research on Climate (MIROC5), General Circulation Model (GCM) of the University of Tokyo, NIES (National Institute for Environmental Studies) and JAMSTEC (Japan Agency for Marine–Earth Science and Technology). Forecast GDP and population under Shared Socio–economic Pathways (SSPs) of IIASA (International Institute for Applied Systems Analysis) of IPCC are incorporated in combination with climate scenarios to generate outlook on food situation and price variation in the arena of climate change.

3.7 Climate change and climatic scenarios

Weather and climate are theoretically different and a typical definition is often mistakenly defined. Weather is a changing circumstance of the atmosphere around us. The climate is an average weather component and on the other hand, climate involves all other components in the climate system including the atmosphere.

3.7.1 Climate and Its Definitions

Climate is interpreted as average statistics of weather, generally over a 30–year interval which is measured based on the magnitude of variations in temperature, humidity, atmosphere pressure, the wind, precipitation, and atmosphere particle count including other meteorological variables in a given region.

As per World Meteorological Organization, the climate is elucidated as an average state of the atmosphere for a time scale (hour, day, month year and so forth) and for a specified geographical region. The average state statistics for a given time range including all derivations from the mean are obtained from ensemble on conditions recorder for many occurrences.

As described by IPCC (Intergovernmental Panel on Climate Change), the climate in a narrow sense is basically delineated in terms "average weather", or as statistical imaginaries in terms of mean and variability of significant quantities over a time period to range from months to thousands or millions of years. The climate in a broader sense is a state, including a statistical description, of the climate system. More simply, it is sometimes pronounced "climate is what you expect; weather is what you are getting. In a universal sense an individual El Nino event could be considered climate; in others, that is the weather.

3.7.2 Climate change

Climate Variability is defined as variations in a mean state and other statistics of the climate on all temporal and spatial scales, beyond individual weather events."Climate Variability" is sometime taken to denote deviations in climatic statistics over a given time period (e.g. a month, season or year) when compared to long-term statistics for the same calendar period. Climate variability is measured by these deviations, which are regularly termed as variance. In essence, climate variability is looked as changes that occur within smaller timeframes, such as a month, a season or a year, and climate change considers changes that occur over a longer period of time, typically over decades or longer (IPCC, 2007).

More concrete definitions:

Climate change in IPCC practice refers to a change in state of the climate that can be identified with statistical tests or by changes in the mean of its properties and that occurs for a period, more particularly decades or longer, change in whether caused by natural changeability or consequent of human activities.

United Nations Framework Convention Climate Change (UNFCCC) differs from IPCC that refers to a change of climate. The climate change is more attributable directly to human activities that alter compositions of global atmosphere and in addition, natural climate variation is observed or compared over time periods.

Global warming is indisputable that is now-a-days obviously witnessed from increasing surface air and ocean temperatures, abundantly melting glaciers and going up to global sea level (IPCC, 2007).

3.7.3 Climate Scenarios: Explanation of RCPs

IPCC generated the projection of climate change scenarios through the application different categorized climate model viz. simple climate model, intermediate complex model, holistic climate model as well as Earth System model. All models were employed to produce a set of a new generation of climate scenarios. Newly defined climate scenarios were denoted by the Representative Concentration Pathways (RCPs) and they were used for climate model simulation in the framework of the Coupled Model Inter–comparison Project Phase 5 (CMIP5) of the World Climate Research Program. All RCPs were presumed that GHG concentrations to atmosphere continue to be higher in 2100 compared to that in the present days. With unwonted and continued emissions of greenhouse gasses, consequently, the globe would be gradually getting warmer that might be driven to detrimental changes to happen in the climate system (Stocker et al. 2013).IPCC AR5 had developed more Representative Concentration Pathways (RCPs) scenarios which would be defined in terms of radiative forcing (i.e., concentrations of radiatively active greenhouse gases, solar radiation, aerosols and albedo that might affect the climate of the earth) and direction of change to climate. They could be denoted by name such as RCP2.6, RCP6.0, RCP4.5 and RCP8.5 (Figure 3.12).

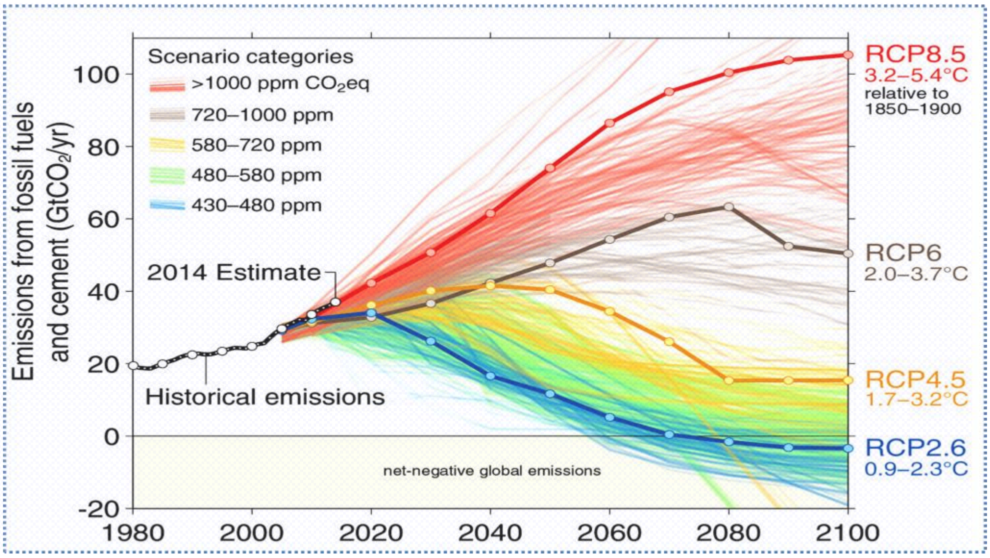

Figure 3.12 Representative concentration pathways (RCPs)
Source: Nature climate Change, 2014

Among the representative scenarios, two contrasting scenarios had been selected for this study: RCP6.0 was medium baseline mitigation and radiative force stabilized at 6.0 W/m^2 (855 ppm CO_2 eq.) and rapid economic growth in Asia while RCP8.5 was described as a high emission pathway and radiative force stabilized at 8.5 W/m^2 (1,370 ppm CO_2 eq.) by

2100.In addition, each scenario had its own fluctuation of climate variables, which would cause the fluctuation of rice production. Since both scenarios project high emission path of GHG from the Asian region, those were, for this reason, more suitable to represent climate change in Asian region including Bangladesh.

3.7.4 Socioeconomic Scenarios: Explanation of SSPs

IPCC also developed the Shared Socioeconomic Pathways (SSPs) in consistent with RCPs–they had been explained on the basis of challenges to the adaptation and mitigation options (Figure 3.13).

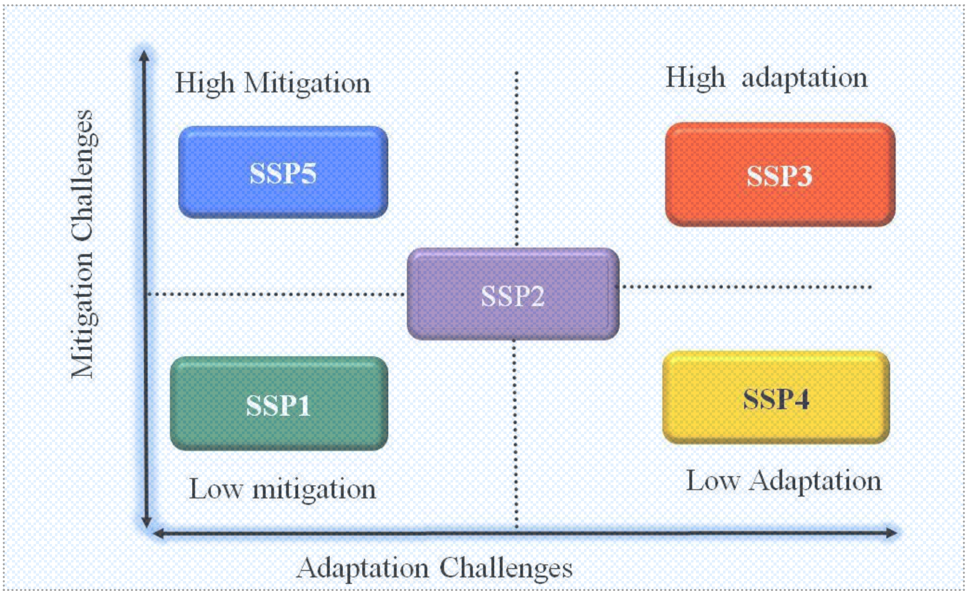

Figure 3.13 Mitigation and adaptation challenges for climate changes

Source: IPCC, 2012

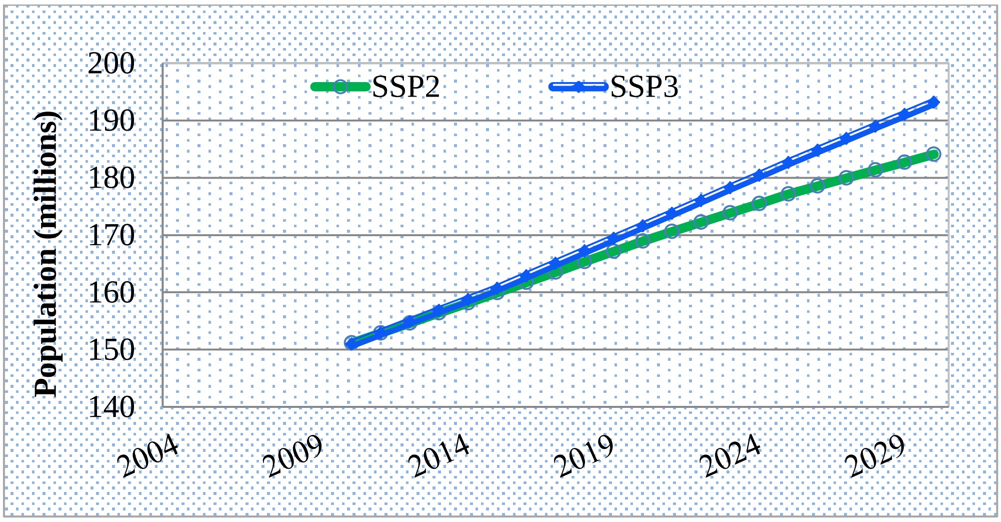

Figure 3.14 Forecasted populations in the scenarios of SSP2 and SSP3

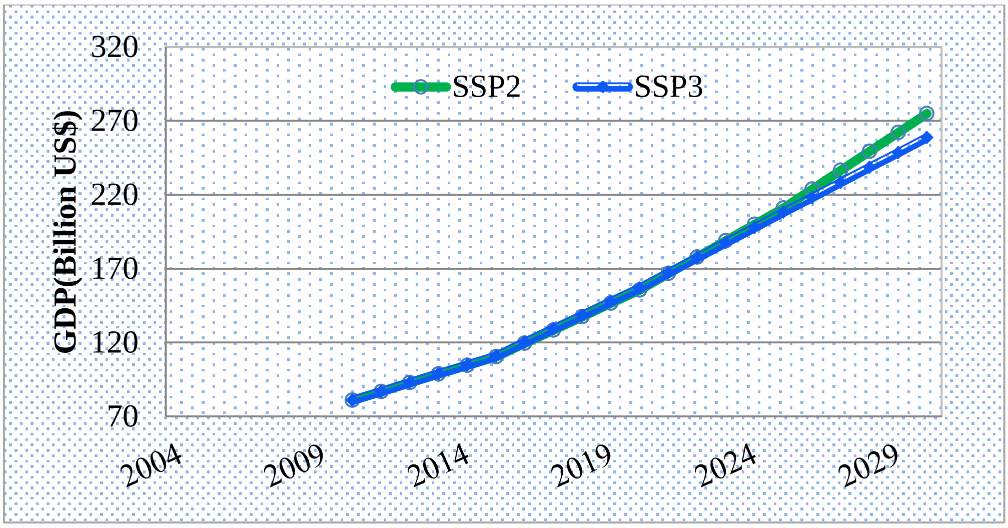

Figure 3.15 Forecasted GDP in the scenarios of SSP2 and SSP3

There had been a set of assumptions about future demographic, economic development and degree of global integration. In addition, IPCC scenarios were proposed to make sense, climate change would affect the scale of economy in the future. To predict GDP scenarios, IPCC also used the assumptions on the structure of economic development in the different region, the entire nation, and sub-national GDP, the sectoral share of GDP including agriculture and productivity, technological advancement and non–climate policy. In the course of future prediction, IPCCs highlighted broadly on the climate change effect on the agriculture in general.

However, it was not exactly known about how accurate the prediction of GDP scenarios would be. IPCC scenarios of GDP were widely accepted and very common to all researchers. To be consistent with the selected RCPs, SSP2 and SSP3 scenarios were chosen among many combinations of the SSPs of IIASA (International Institute for Applied Systems Analysis) shown in the figure 3.14 and 3.13. SSP2 represented intermediate challenges in which population and GDP did increase moderately. In contrast, SSP3 represented high mitigation and adaptation challenges in which population growth was high and GDP growth was very low but a de–globalized region attempted to achieve food security within its own region. In the final stage of model calibration, RCP and SSP scenarios were incorporated into the supply and demand model simultaneously to predict outlook of rice supply, the variations of market price and per capita consumption from 2010 to 2030.

Similarly, a linear approximation approach was applied to extrapolate the GDP deflator (GDPD) in the prediction period. A linear approximation method is also used to extrapolate world price of rice and exchange rate, which were used in the forecast period.

3.7.5 Criteria for selection of MIROC5 in the IPCC 5th assessment report

Climate–Sensitive (CS), which was defined as global mean surface air temperature that responses to a doubling of CO_2 concentration in the atmosphere, was an essential information that more meticulously highlighted on adaptation and mitigation policies in order to decline climate changes (Knutti and Hegerl, 2008). The variation in a CS in multi–model ensemble (MME) was created by employing different model structures or different physical parameterization approaches and resolutions. For that reason, this was recognized as ‘‘structural uncertainty’’. The ‘‘parametric uncertainty’’ was another extensive uncertainty. MIROC5 developed a perturbed physics ensemble (PPE) to connect atmosphere–ocean general circulation model (CGCM) to investigate a parametric uncertainty of climate sensitivity (CS) (Murphy *et al.* 2004). The previous PPE approaches were considered to be significantly useful, but they were scrutinized to have substantial limitations, nevertheless. Most of the previous PPE studies mainly employed atmosphere/slab-ocean (mixed layer ocean) GCMs (ASGCMs) rather than coupled atmosphere/full-ocean. A few studies had performed CGCM PPEs to move beyond this limitation of PPEs in ASGCMs. This might be because perturbations in parameters could lead to large radiation imbalances at the top of the atmosphere and climate drifts. MIROC5 developed a method to prevent climate drifts in PPE experiments using the MIROC5 CGCM without flux corrections. At the same breath, MIROC5 flounced 10 parameters in atmosphere and surface schemes. The range of CS was not so large (2.2–3.2 ^{0}C). Previous studies of PPEs mainly used ASGCMs and flux corrections, which could significantly affect the climate biases and projections. Previously, no methodology had been created to be useful across modeling groups to perform PPE with CGCM and without flux corrections. The greatest concern that was Top of Atmosphere (TOA) imbalance to cause large climate drifts. MIROC5 developed a method to control TOA imbalance in the CGCM PPE without flux corrections. Therefore, MIROC5 was distinguished to develop reasonably more accurate climate scenario (Shiogama *et al.* 201).

3.8 Estimation Method

Secondary data were used in this research from the aforesaid data sources. Ordinary Least Square (OLS) methods and Two Stage Least Square (2SLS) were the most possible methods to estimate the suitable parameters of supply and demand systems. In several equations of the supply and demand system analysis, endogenous variables were used as explanatory variables. To estimate the parameters of those equations, 2SLS was far more necessary in order to avoid the problem of biased estimation.

However, in some cases, many parameters estimated by using 2SLS method would be produced out of reasonable range that acutely affected the result of long term projection. The main purposes of this piece of the study were the long term projection of the supply and demand of rice in Bangladesh. To eliminate the strange problem in system analysis due to unreasonable parameters; OLS estimation method was adopted used in order to estimate the parameters of the system equation. Based on data limitation and the consistency of the time series dataset, the parameters of the equation (3.4) through equation (3.11) had been estimated using OLS for the time period from 1977 to 2009. Trial and errors approaches were applied to obtain the more suitable model (Figure 3.1). OLS was found to perform well when the expected model criteria were satisfied. The value of adjusted R^2 of all functions estimated with ranged from 0.75 to 0.99 was sufficiently high to explain predicted variables. In addition, the estimated model was checked for the presence of serial auto–correlated error terms by applying Durbin–Watson (DW) d and h statistics for functions with and without lag dependent variables, respectively. DW values ranging from 1.60 to 2.50 indicates that there was no serial correlation, so the results of parameter estimates were representative enough to explain the phenomenon of the prediction model. The prediction period was extended based on the econometric analysis from 2010 to 2030. To end with, the market clearing price was obtained when the difference of net supply and demand was equal to zero and solving the model by the Gauss-Seidal algorithm (Meyer. *et al*. 2006).

In the empirical analysis of food policy model, parameters of public import, private import, and stock change were also estimated using OLS for the time period from 1994 to 2009. The necessary data for food policy operation was also limited and the policy models could be reasonably estimated from 1994 to 2009 (equation (3.14, 3.15 and 3.18)). However, OLS method was not applicable to estimate the parameters of procurement and distribution. The consideration was that procurement and distribution were subject to the constraints of the public stock level. For this reason, Tobit model, which could take into account of the upper limit of public stock, was applied to estimate the procurement and distribution functions (equation (3.13 and 3.16)).

3.9 Model Selection Criteria

3.9.1 Durbin–Watson test of serial autocorrelation

Durbin–Watson (DW) statistic is a test measure for first order serial correlation $AR(1)$ which is measured as linear association among successive residuals of the regression model. The hypothesis for Durbin–Watson test statistics can be exhibited such as:

$H_0 : \rho$ =0, there prevails no first–order serial correlation.

$H_A : \rho \neq 0$, there is first order serial correlation in the model.

$$u_t = \rho u_{t-1} + \varepsilon_t \tag{3.21}$$

where, u_t is regression residual in the period t ; u_{t-1} is residual in the preceding period and ρ is the linear association between these two residual. Assuming that the error terms are normally distributed ($u_t, u_{t-1} \sim N(0,\sigma^2)$) and the error terms are stationary. Then the Durbin–Watson statistic can be mathematically noted as below:

$$DW = \frac{\sum_{t=2}^{T}(u_t - u_{t-1})^2}{\sum_{t=2}^{T} u_t^2} \tag{3.22}$$

In econometrics, Durbin –Watson test indicates that DW value usually ranges from 0 to 4. If a value is 2, it is supposed that there is no autocorrelation and a value between 0 to <2 indicate that there is positive autocorrelations. The occurrence of both autocorrelations is common in the time series data. Furthermore, >2 to 4 is the negative autocorrelation which not very common. However, the thumb rule suggests that the test statistics value ranging from 1.5 to 2.5 is generally acceptable.

Furthermore, it is assumed that if the regression model includes the lagged dependent variable, conveniently there is a simple alternative approach to DW statistics. This can be defined as h statistics which is formulated from DW statistics as below:

$$h = \left(1 - \frac{DW}{2}\right)\sqrt{\frac{T}{1 - T[se(b_{lag})]}} \tag{3.23}$$

where, DW is the usual DW test, T is the total number of observation and $se(b_{lag})$ is the square of the standard error of the estimated parameter of the lagged dependent variable. The test statistic can be assumed to be standard normal distribution $h \sim N(0,1)$. The test of the null hypothesis of autocorrelation implies that the test value must be compared with a critical value from the standard normal table(Gujarati, 2004).

3.9.2 R–Square and adjusted R–Square

R–square may be described to measure the fitness of a regression model that could explain the variation in the dependent variable under the assumptions of sample explanatory factors. R–square can be calculated by the following formula:

$$R^2 = 1 - \frac{ES_{res}}{TS_{tot}} \tag{3.24}$$

where, R^2 is the goodness of fit of regression that indicates the fraction of the dependent variable which could be explained by the incorporated regressors in the model. ES_{res} is the square sum of residual obtained from sum square of a difference between observation of the dependent variable and estimated value from regression. TS_{tot} $(RS_{\exp} + ES_{res})$ is the total sum square of residual sum square ES_{res} and explained sum square $RS_{\exp}$. Explained sum square $SS_{\exp lained}$ is obtained from sum square of the difference between estimated value from regression and mean of dependent variables. A value of R–square (in equation (3.24)) ranges between zero to one. The statistic of R–square is equal to one that indicates the perfect goodness of fit. If R–square is zero, it is only meaning that there is no better fit of the model. The problem occurs in explanation of R–square, possibly because of that R–square never decrease with the increase of explanatory variables in the regression. For reasonable explanation power of the model, the R–square that must be adjusted with the addition of regressors, is commonly denoted as $\overline{R}^2$–square. The following notation is for adjusted R–square:

$$\overline{R}^2 = 1 - (1 - R^2)\frac{T-1}{T-k} \tag{3.25}$$

where, T is the number of observation and k is a number of the coefficient in the model. It is important to note that adjusted R–square is always slightly smaller than adjusted R–square (Gujarati, 2004).

3.9.3 Final test criteria

A number of the model had been employed in the supply and demand system study. To understand final test statistics easily, it was more convenient to adopt some important model as an example in order to give a general image regarding the fitness of the model with an actual observation. The better fit with actual observation meant that there was minimal variance and the model was supposed to perform well in the process of market mechanism analysis. As an example, the figure 3.16–3.18 displayed the better fit of the selected regression model. All remaining functions were tested in a similar way.

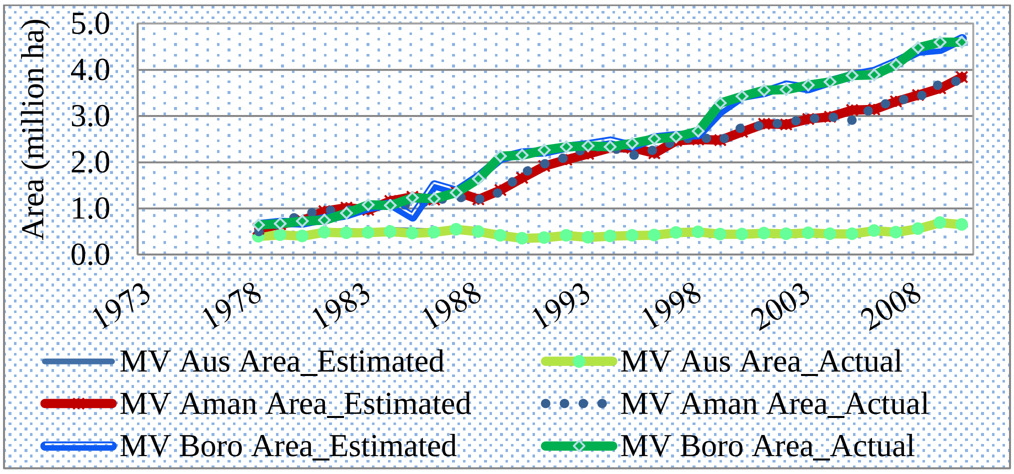

Figure 3.16 Final test statistics for MV Area function in three different seasons

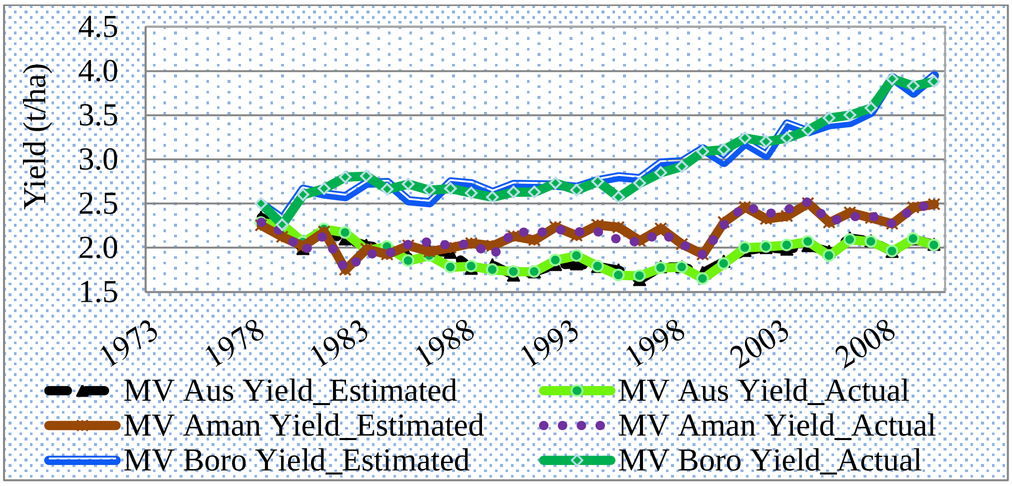

Figure 3.17 Final test statistics for MV yield function in three different seasons

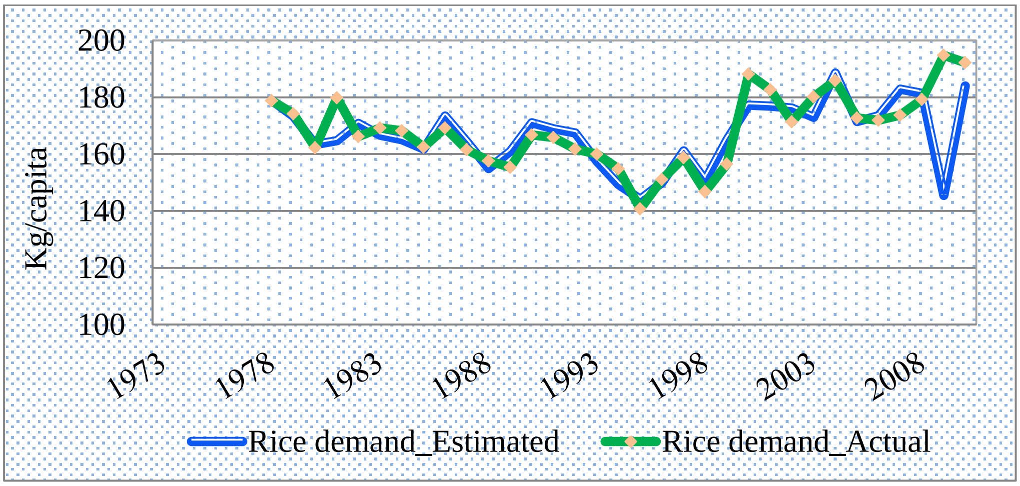

Figure 3.18 Final test statistics for rice per capita demand function

CHAPTER–IV
CLIMATE IMPACT ON SUPPLY AND DEMAND

This study was designed to elucidate the impact of climate change on rice production, market price, and demand. In order to achieve the objectives, a supply and demand model of rice in Bangladesh which had been constructed was elaborately delineated in Chapter–III. The supply and demand model was simulated using emission scenarios (RCP6.0 and RCP8.5) and socioeconomic scenarios (SSP2 and SSP3). The supply and demand model had been synthesized regarding the impact of climate changes in the market mechanism, in which the variability of market price would be figured out through the interaction of supply and demand, had been interpreted more detail as below .

4.1 Estimation of Model Parameters and Elasticities

Estimated parameters and elasticities of yield and area were given in Tables 4.1 and 4.2. The stock change, import, and demand elasticity of rice were estimated and shown in Table 4.3.

4.1.1 Estimation of yield functions

The parameters and elasticities of seasonal yield by rice varieties were estimated repeatedly using trial and error with the ordinary least square method. Trial and error approach was stopped when model criteria were satisfied. The estimated yield equation showed that all of the adopted variables in the estimated functions were statistically significant at the different level of significance (Table 4.1). In econometric estimation, the adjusted *R*-square would range from 0.85–0.93 and Durbin–Watson value for first order autocorrelation statistics would range from 1.6–1.9. Therefore, all models were econometrically good fit and there had not been existed the serial autocorrelation in the model. Table 4.1 further demonstrated that proxy for technological advancement, irrigation, and machinery facilities which had a positive role on upward trending of yield by varieties in all respective seasons, and which further exemplified the effort of huge research investments and rapid extensions of the modern technology at farmers' hand. On the other hand, the elasticity illustrated that the increased temperature in May and June (–1.42 and –0.59) had an enormous negative impact on yield of modern *Aus* meaning that 1% higher temperature decrease 1.42% yield in May and 0.59% in June. Even though rainfall in May and July were significant in the yield model of modern *Aus*, the effect on modern *Aus* yield was not so stronger (Table 4.1). The increased rainfall in April (0.06) and solar radiation in May (0.46) had also a positive influence on the yield of local *Aus*. In addition, higher solar radiation in March had a negative significant effect on local *Aus* yield implying that 1% increase solar radiation reduces 1.86% of local *Aus* yield.

According to rice plant breeder, *Aman* was the wet season and more photosensitive crop. In the case of Modern *Aman* rice, higher solar radiation in July was most likely to enhance the growth of the plant in modern *Aman* indicating that 1% increase solar radiation could increase 0.51% yield in modern *Aman*. Furthermore, the high temperature in June (–2.19) and October (–0.90) coupled with high solar radiation (–0.91) was a great concern, implying the consequences that caused the yield of this crop to decline detrimentally. In October, modern *Aman* started a panicle initiation and would bear booting stage. Similar to modern *Aman*, the increased temperature in June (–0.76) and July (–2.28) caused a massive hazard on local *Aman* yielding. In contrast, merely rainfall in October (0.05) for Local *Aman* was a great support for increasing water supply when local *Aman* happened to initiate flowering (Table 4.1).

In the case of modern *Boro*, the planting period of *Boro* rice was accomplished in November through January and harvesting period was carried on in April through May. Sometimes, *Boro* season was also called winter season crop. The result in table 4.1 depicted that excessive rainfall in March (-0.05) and higher solar radiation in January (-2.01) had a negative consequence on the yield of modern *Boro*. The elasticity of Modern *Boro* rice signified that high rainfall in April (0.09) enhance the yield of modern *Boro* especially those plots were transplanted in late February. Even though rainfall in yield model of modern *Boro* was statistically significant, the magnitude of elasticity was not so stronger to determine the higher yield. This could be a possibility because modern *Boro* had been intensively irrigated rice in Bangladesh. It was pretty impressive that higher temperature in November (2.47) and April (1.10) had a stronger influence on Local *Boro* yielding. On that account, in winter *Boro* crop, increasing temperature showed huge favourable results to augment yield performance. Table 4.1 also exhibited that 1 unit increase in temperature in November and April would increase 2.47% and 1.10% yield in Local *Boro*, respectively.

Therefore, increasing the temperature in winter season had greatly positive effect on the plant growth and grain formation in *Boro* season. In conclusion, the results of elasticities of climate variables in the yield models suggested that increasing temperature constantly put rice production in great challenges, especially in *Aus* and *Aman* seasons. Over all, higher temperature and erratic rainfall had a great alarming for rice production in Bangladesh because climate variables had thecertainly vital role on plant growth, tillering, and grain formation stages to determine the magnitude of the yield of all varieties in three rice–growing season.

Table 4.1 Estimates of yield functions (equation (3.3))

Yield	Intercept	Trend (1977=1)	Seasonal climate variables				Dummy variables	$AdjR^2$ DW
AuM	6.32*** (7.46)	(1994=1) 0.06*** (12.18) [0.14]	Tmp05 –0.09*** (–4.92) [–1.42]	Tmp06 –0.04* (–1.64) [–0.59]	Rf05 –0.0004** (–2.62) [–0.06]	Rf07 –0.0003** (–2.40) [–0.08]	D079	0.88 1.77
AuL	2.07*** (3.68)	0.017*** (15.26) [0.29]	Rf03 –0.002*** (–3.39) [–0.07]	Rf04 0.0005*** (2.75) [0.06]	Sr03 –0.004*** (–3.18) [–1.86]	Sr05 0.001* (1.66) [0.46]	D781 D958	0.91 2.18
AmM	8.84*** (7.73)	0.02*** (10.84) [0.15]	Tmp06 –0.165*** (–6.58) [–2.19]	Tmp10 –0.09*** (–3.76) [–0.90]	Sr07 0.003*** (4.43) [0.51]	Sr10 –0.003** (–2.64) [–0.91]	D770 D87 D97 SHIFT09	0.89 1.65
AmL	4.23*** (3.98)	0.011*** (10.02) [0.15]	Tmp06 –0.034* (–1.89) [–0.76]	Tmp07 –0.10*** (–2.95) [–2.28]	Rf10 0.0003** (2.81) [0.05]	Sr07 0.002*** (3.05) [0.54]	D978 D04 D07 SHIFT09	0.86 1.73
BoM	7.97*** (3.35)	0.04*** (12.4) [0.28]	Rf03 –0.004*** (–3.22) [–0.05]	Rf04 0.002*** (3.97) [0.09]	Sr01 –0.018** (–2.54) [–2.01]		D790 D823 SHIFT07	0.93 1.60
BoL	–4.61 (–4.06)	0.02*** (9.53) [0.44]	Tmp04 0.14*** (3.42) [2.47]	Tmp11_1 0.07** (2.14) [1.10]			D834 D889 D03	0.85 1.90

***,** and * indicates the level of significance at 1, 5 and 10%.

Values in ( ) and [ ] indicates $t-$values and elasticities, respectively. $AdjR^2$ is adjusted $R-$square and DW is Durbin–Watson values

AuM =Aus Modern, AuL=Aus Local, AmM =Aman Modern, AmL=Aman Local, BoM =Boro Modern, Bol=Boro local. Tmp01......Tmp12, Sr01……Sr12 and Rf01……Rf12 indicates temperature, solar radiation, and rainfall in January through December, respectively. Tmp11_1 indicates 1–year lag in November temperature.

4.1.2 Results of estimated functions of planted area

In Bangladesh, there had been substantial data limitation of specified planted area. In national statistics, the harvested area was considered as planted area. Planted areas (harvested area) functions of three seasons were specified as a linear function based on the adaptive expectation model. The explanatory variables were time trend, one–year lagged planted area and farm price, and one–year lagged rainfall for *Aman*, one and two–years lagged rainfall for both *Aus* and *Boro* seasons. Most of the selected variables in area functions showed statistical significant in the model estimation. In econometric estimation, the adjusted *R*–square ranged from 0.93–0.98 and Durbin–Watson h statistics ranged from 1.95–2.5. Therefore, all models were econometrically good fit with high *R*–square and h statistics of D–W value more strongly confirmed that there had not been the problem of serial autocorrelation in the model. The estimated elasticities of planted area could be viewed in Table 4.2 with detail notation. The elasticity of lagged planted area was around 0.69 for Modern *Aus* indicating the approximately stable condition for area devotion to modern *Aus* from the previous year. The elasticity of lagged year's farm price (0.10) indicated that price was an important role player in making the decision regarding allocation of lands and had a significantly positive effect on farmers' behaviors to cultivate modern *Aus*. Lagged rainfall in November (-0.06) had also a negative consequence on area allocation to modern *Aus*.

Local *Aus* area had a strong downward trend (–0.32) and elasticity of lagged area (0.32) also supported the notions that areas continued shifting to modern *Aus* varieties or *Boro* crops or other crops due to lower yield. Thus, there was no robust responsiveness between planted area and lagged area (0.218) due to strong negative trend. On the contrary, this variety was locally popular in many parts of the country to consume; hence lagged price (0.154) had still a significant influence on the motivation of local *Aus* cultivation. In addition, the lagged price and rainfall elasticity in April took over the farmers' decision in favor to cultivate the local *Aus*. Rainfall in May (–0.04) showed negative consequence to local *Aus* cultivation but the magnitude of effect was not so ghastly worsened.

In the case of modern *Aman*, the positive elasticity of trend (0.24) indicated modern *Aman* area trending in upward. The elasticity of lagged harvested area was nearly 0.71 for Modern *Aman* meaning that farmers likely made a plan to cultivate 71% of planted land from the previous year. The elasticity of lagged year's farm price (0.18) played an abundant role in favor of modern *Aman* cultivation implying that 10% increase price in last year could lead to 18% more area allocation to modern *Aman* in the current year. Lagged rainfall in both October (0.04) and November (0.02) had a positively strong influence on modern *Aman* cultivation. Local *Aman* cultivation had also the unbroken downward trend (–0.13). Even though local *Aman* area had been a strong declining trend, the elasticity of lagged area (0.61) and lagged price elasticity (0.18) indicated that availability of area and goods prices predominantly encouraged the farmers to cultivate local *Aman.* In addition, the elasticity of rainfall in May (0.05) had a positive sign on local *Aman* cultivation (Table 4.2).

Modern *Boro* cultivation had been an emerging sector that shared more than 50 to total rice production in Bangladesh and contributed greatly to determine the sustainable food security (BBS, 2013). The elasticity of lagged area (0.69) and rainfall in August (0.5) and October (0.06) were the main concerns to control the farmers' behaviors in favor of modern *Boro* rice cultivation. Similar to Local *Aman*, lagged area elasticity of local *Boro* area (0.69) had a stronger control over that could motivate the farmers to cultivate the local *Boro.* The lagged price elasticity of both modern and local *Boro* had a considerable influence on farmers' decision in favour of area allocations even though those were not statistically so much powerful

In all rice growing seasons, availability in the area and climate variable especially rainfall had a greater influence on planted area of modern and local rice cultivation. Even though the price had also the positive signal for all the case of rice cultivation, it had no statistically significant effect on the allocation of cultivated land under modern and local *Boro* cultivations. A reason could be voted that *Boro* was an emerging season for its seasonal potential, higher share to total production and out–yielding capacity that certainly could contribute far better to endure the food security. The government also would continue to emphasize more greatly on intensive practice of *Boro* cultivation through higher investment on input and irrigations.

Table 4.2 Estimates of area functions (equation (3.4))

Area	Intercept	Trend	Area (t-1)	Price (t-1)	Climate variables (t-1 or t–2)		Dummy variables	$AdjR^2$ DW
					R11_2		D89	0.93
	-1215916		0.70***	6.6***	–1095***		D97	2.37
AuM	(–5.89)		(12.56)	(2.70)	(–5.14)		D05	
			[0.69]	[0.10]	[–0.06]		D078	
	1705528	–28372***			Rf04_1	Rf05_1	D89	0.99
AuL	(3.27)	(–3.25)	0.31*	27.3**	334**	-222**	D94	1.79
		[–0.32]	(1.76)	(2.18)	(2.09)	(-2.11)	D963	
			[0.32]	[0.13]	[0.03]	[-0.04]		
	-395929				Rf10_1	Rf11_1		0.99
AmM	(–1.66)	30139**	0.74***	51.4**	515**	1654*	D87	2.14
		(2.22)	(5.42)	(2.32)	(2.25)	(1.70)		
		[0.24]	[0.71]	[0.18]	[0.04]	[0.02]		
	1520198				Rf05_1		D889	0.98
AmL	(1.13)	–43769*	0.59***	109.9**	915**		D98	2.28
		(–1.68)	(4.14)	(2.41)	(2.28)		D99	
		[–0.16]	[0.61]	[0.18]	[0.05]		D07	
		36034**			Rf08_2	Rf10_2	D85	0.99
BoM	-449048	(2.42)	0.73***	36.3	336**	900***	D878	2.50
	(–1.91)	[0.25]	(6.86)	(1.57)	(2.03)	(4.05)	D979	
			[0.69]	[0.11]	[0.05]	[0.06]	D04	
					Rf01_1		D77	0.98
BoL	327187		0.68***	4.34	–2113*		D791	1.95
	(3.30)		(9.26)	(1.42)	(–1.82)		D84	
			[0.69]	[0.12]	[–0.04]		D049	

***,** and * indicates the level of significance at 1, 5 and 10%.

Values in ( ) and [ ] indicates $t-$values and elasticities, respectively. $AdjR^2$ is adjusted $R-$square and DW is Durbin–Watson values

AuM =Aus Modern, AuL=Aus Local, AmM =Aman Modern, AmL=Aman Local, BoM =Boro Modern, Bol=Boro local. Tmp01……Tmp12, Sr01……Sr12 and Rf01……Rf12 indicates temperature, solar radiation, and rainfall in January through December, respectively, *and Rf…_1 or Rf…_2 means 1 year or 2 year lag.*

4.1.3 Results of estimated demand, stock change, import, and price link functions

According to microeconomics, the sign of estimated parameter of rice price was most possibly negative in rice demand (Table 4.3). Rice was the staple dish in the daily diets and the main source of calorie intake in Bangladesh. Price elasticity of rice demand (–0.48) was further verified that rice demand could be indicated by inelastic goods because the absolute value of price elasticity of rice was estimated as less than one. A 10% increase in rice price would likely reduce 4.8% of rice consumption.

On the other hand, wheat had been the second major food in the order of daily diet and much closer substitute to rice. Substitute price elasticity of wheat indicated that a 10% rise in wheat price could possibly increase 2.3% of rice consumptions. Even though the income per capita was not strongly significant, the negative sign of the elasticity indicated (–0.13) that with an increase in income, demand for rice could be referred to by inferior good. Recently GDP growth in Bangladesh was absolutely in rising trend and rising income per capita would tend to motivate the household more immensely reallocating the consumption expenditure. This indicated that demand for non–cereal such as the fishes, the meats, and the egg was more probably to increase in rapid trend (Murshid *et al*., 2008).

The stock was also an important player in the market supply of foodgrain. The private stock had been dealt on basis of price speculation or arbitrage in order to make a profit. Stock usually started to increase when the price would go down whereas stock was released hastily to market when the price moved to rise (Kobayashi and Furuya, 2011). The stock change could be explained more properly with price change and change in production. Both the independent variables in stock change function validated the general postulation and were estimated to be statistical significance.

Likewise, import function, which was achieved with an opposite sign of parameters, were consistent with the prior expectation meaning that increased in production (–1.70) and the ratio of world price to retail (–0.86) was more likely to cut back the quantity of import. In Bangladesh, the price was headed in the upstream transmission that retail price could possibly control a direction of farm price movement. Statistically, the estimated parameter of price function also could explain the corresponding increase or decrease of farm price due to movement of retail price. A 10% increase of retail price would increase a 4.1% of farm price.

Dummy variables, which were chosen, based on statistical significance, exhibited special policies implementation, climate incidence (such as extreme events, cyclone, flood, the drought year), biotic stresses to the crops, and other external factors such as technical changes. However, the inclusion of dummy variables in the model facilitated the more explanatory power of model to estimate statically significant parameters in the estimation of yields, areas and other systems functions (Appendix–A).

Table 4.3 Estimates of import, stock change, demand, and price link functions (equation (3.7–3.8), equation (3.10), and equation (3.12))

Equation	Constant	Variable estimate	Variable estimate	Variable estimate	Dummy variables	$AdjR^2$ DW
Demand (Per capita)	229*** (9.68)	RPR_t –0.005*** (–4.32) [–0.48]	PPW_t 0.004*** (2.82) [0.23]	GDP_t/POP_t –0.002 (–1.52) [–0.13]	D779 D826 D927 D045 D08	0.75 2.18
Stock change	261002 (1.44)	ΔQR 0.82*** (12.18) [1.51]	ΔRPR –71.81** (–2.30) [–0.05]	*TREND* –80704*** (–4.83) [–4.38]	D956 D08 D09	0.93 2.03
Import	2465085*** (4.87)	QR_t –0.04* (–2.00) [–1.70]	WPR_t/RPR -442073* (–1.96) [-0.86]		D7794 D97 D001	0.60 2.15
Price linkage	639 (1.53)	PRP_t 0.41*** (11.45) [0.85]			D882 D07 SHIFT08	0.92 2.08

***,** and * indicates level of significance at 1, 5 and 10%

Values in ( ) and [ ] indicates $t-$values and elasticities, respectively

Δ indicates the change in period of t and $t-1$

4.2 Simulated Results and Discussions

4.2.1 Assumptions of simulation: about supply and demand under climate change

The econometric model estimation was accomplished from 1977 to 2009 and the term for future outlook was taken in midterm from 2010 to 2030. The assumptions of the simulation were as follows; i) the forecast growth value of GDP deflator was the average annual growth between 2000 to 2011, ii) the growth value of GDP scenarios was the average annual growth between 2010 to 2030 and the growth value of population was the average annual growth between 2010 to 2030 (IPCC, 2013), iii) the growth value of exchange rate was the average annual growth between 2000 to 2009 for extrapolation until 2030, iv) the linear trend of yield functions were continued which account for the technologies progress as average yield had been trending upward, v) The trend applied in area functions was included to be flat, vi) Each climate scenarios had its own type of fluctuation that affects the trend of supply and market price determination, viii) finally the estimated parameters were assumed to be fixed.

4.2.2 Simulation results of supply and demand model

With the application of equilibrator as discussed in methodology chapter, the convergence of demand and supply had reached through market clearing price when the difference between supply and demand was zero. Figure 4.1–4.16 showed the simulated result of seasonal yield, area, and supply, demand and equilibrium market price of rice in Bangladesh for the period of 2010 to 2030. Moreover, the seasonal yield of all varieties showed the increasing trend over the period 2010 through 2030, but the yields substantially would fluctuate in both RCP6.0 and RCP8.5, nevertheless. Apparently, it appeared that magnitude of fluctuation would slightly be higher in RCP6.0 than in RCP8.5 which would be elucidated in the following section. The analysis revealed that seasonal temperature, rainfall and solar radiation, more particularly, temperature and erratic precipitation would cause a greater degree of fluctuation in yields.

The area under modern *Aus* would follow the unbroken downward trend from 2010 and continue until 2020, then reach a more steady flow in the later period of simulation until 2030. The area under modern *Aman* and *Boro* displayed completely continuous trending in upward and would be peaked up after 2010, then would become steadily horizontal over the later part of the simulation under both scenarios. On the other hand, seasonal areas under LV demonstrated a strong declining trend and would be arrived at a slower horizontal flow in the period of 2010 through 2030 in both RCP6.0 and RCP8.5. As a result, increasing yield and more area under modern crops would be eminently induced to boost up national rice production. It was an important to note that strongly negative trend in the area under *Aus* season denoted the area shift to modern *Boro* rice and some other non–rice crops (Maize and Tobacco) as there had been a bit overlapping between *Aus* and *Boro*. Again the simulation stated the proposition that increasing trend of production would increase the stock of rice and thereby save the extra spending for import of rice. Bangladesh would opportunely be moved to being the state of sustainable food producer and surprisingly emerge as exporting country in the simulation period.

With the greater fluctuation of per capita demand and market price, figure 4.15 showed the per capita rice consumption would slightly decrease in the simulation period under RCP6.0 and SSP2 as well as RCP8.5 and SSP3. Rising national income and food diversification would cause rice consumption to decline. Furthermore, figure 4.15–4.16 showed the simulated result of equilibrium farm and retail price of rice. Both prices were determined as market clearing price from the convergence of supply and demand in the simulation. Finally, the simulation supportively remarked that climate change would have an enormous impact on market price variations through supply and demand systems.

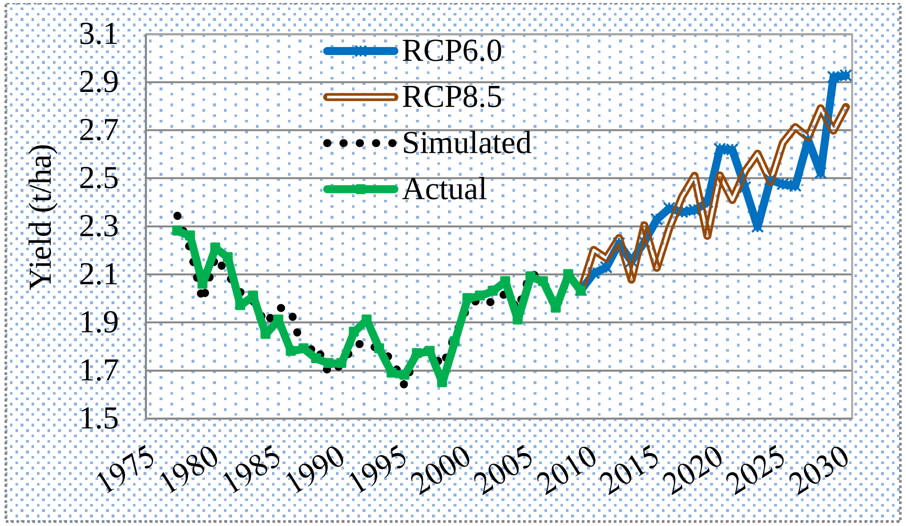

Figure 4.1. Forecast yield of modern *Aus*

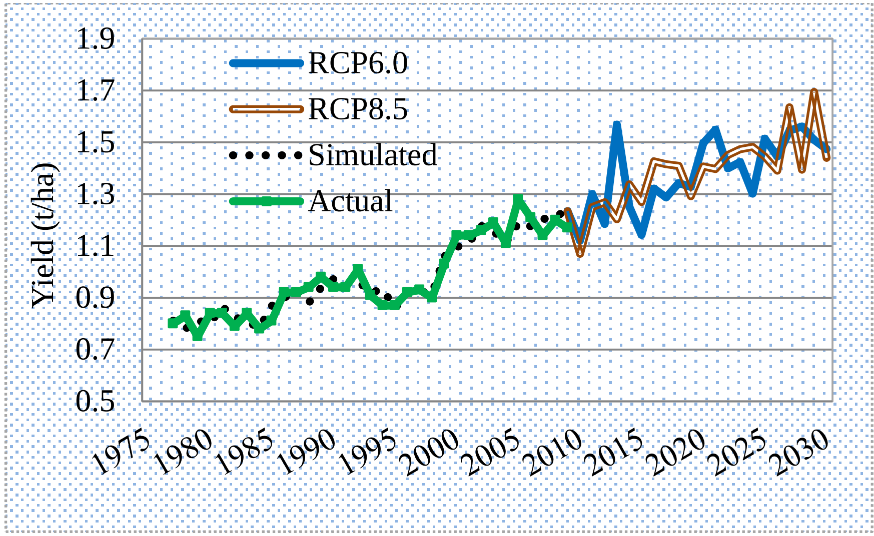

Figure 4.2. Forecast yield of local *Aus*

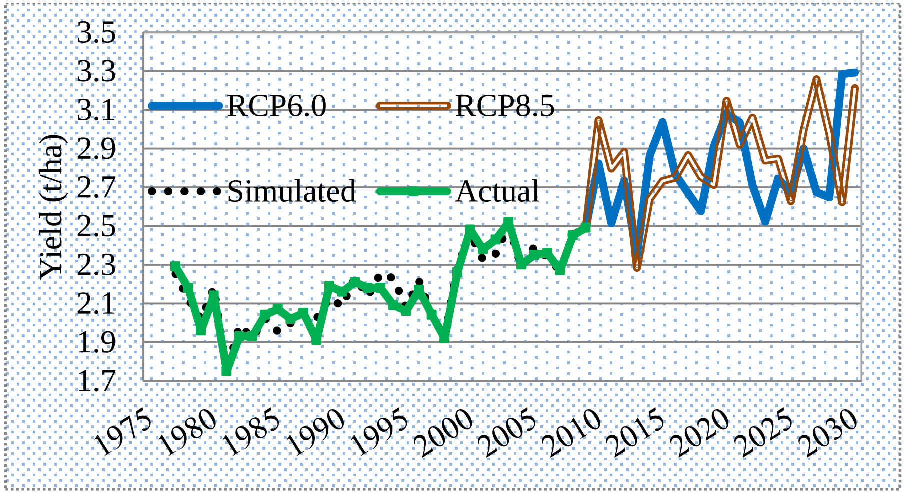

Figure 4.3. Forecast yield of modern *Aman*

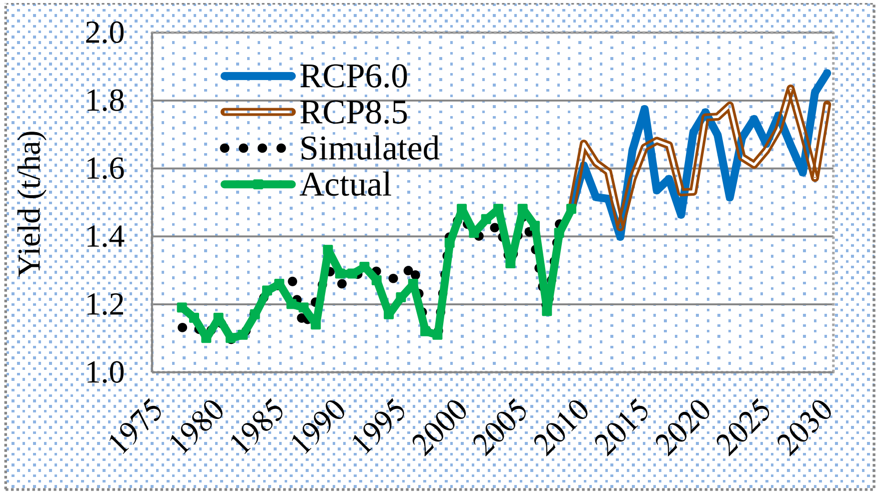

Figure 4.4. Forecast yield of local *Aman*

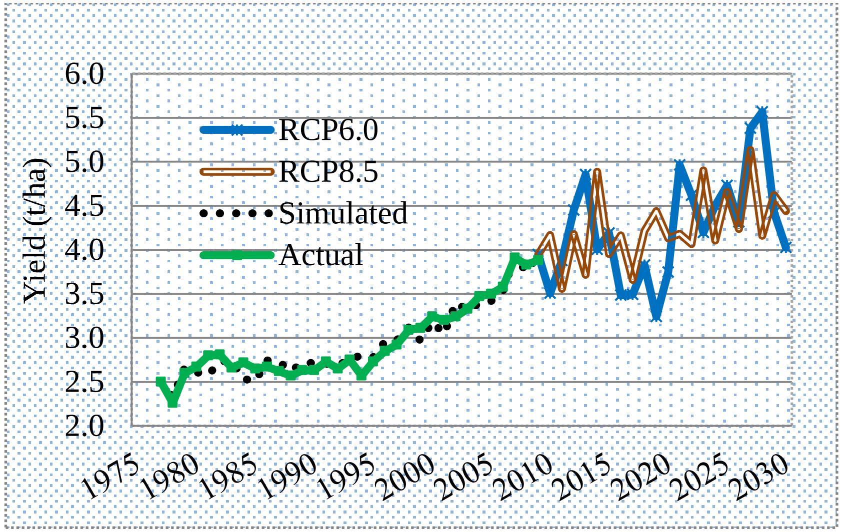

Figure 4.5 Forecast yield of *Boro* modern variety

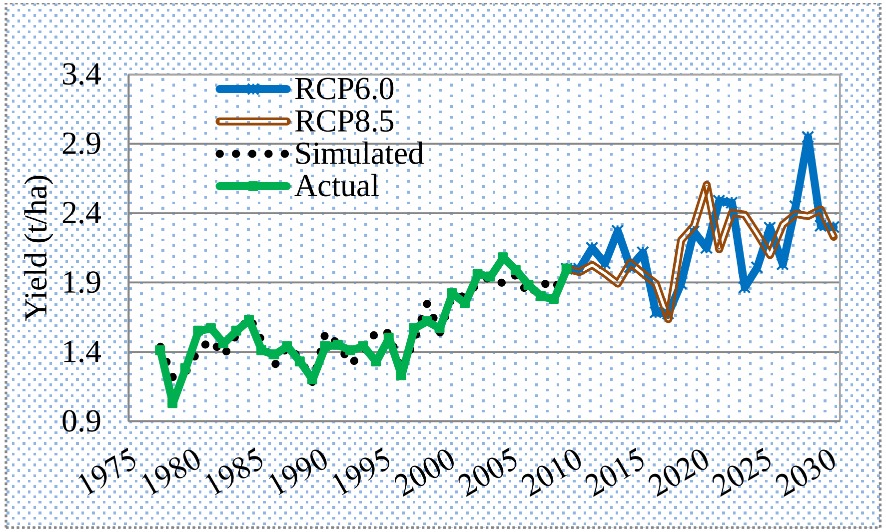

Figure 4.6 Forecast yield of *Boro* local variety

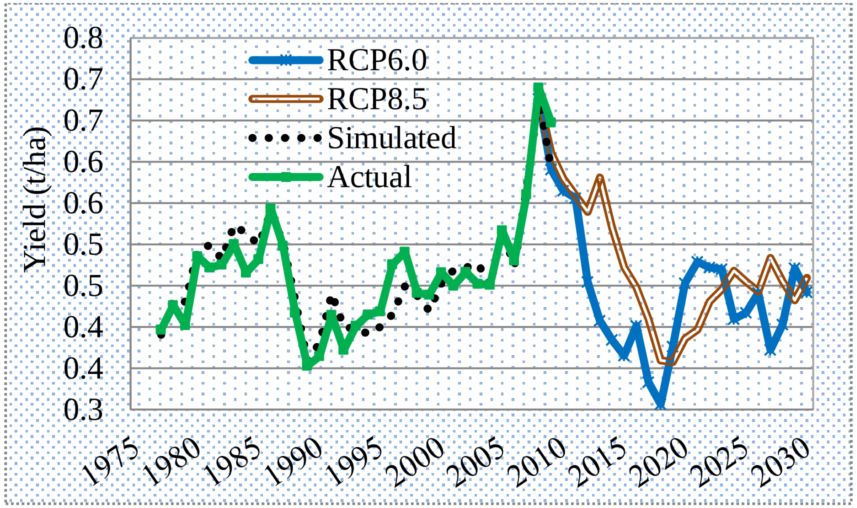

Figure 4.7. Forecast area of modern *Aus* variety

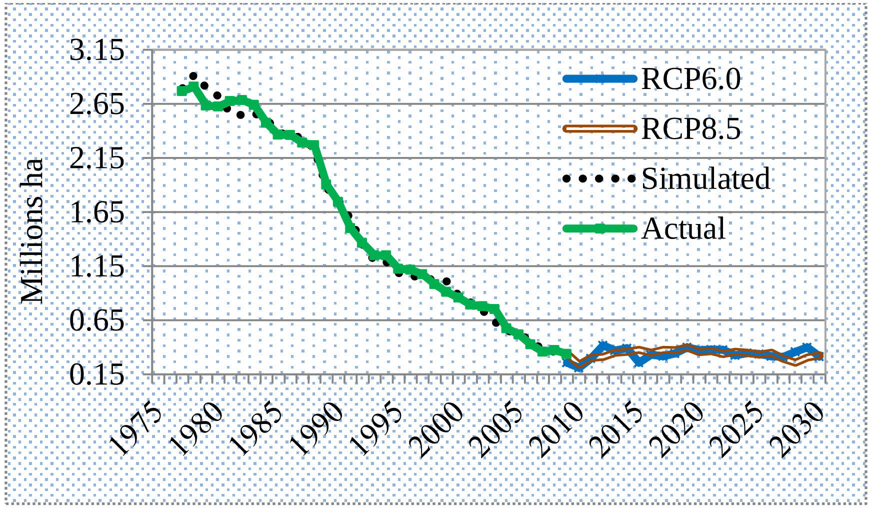

Figure 4.8. Forecast area of local *Aus* variety

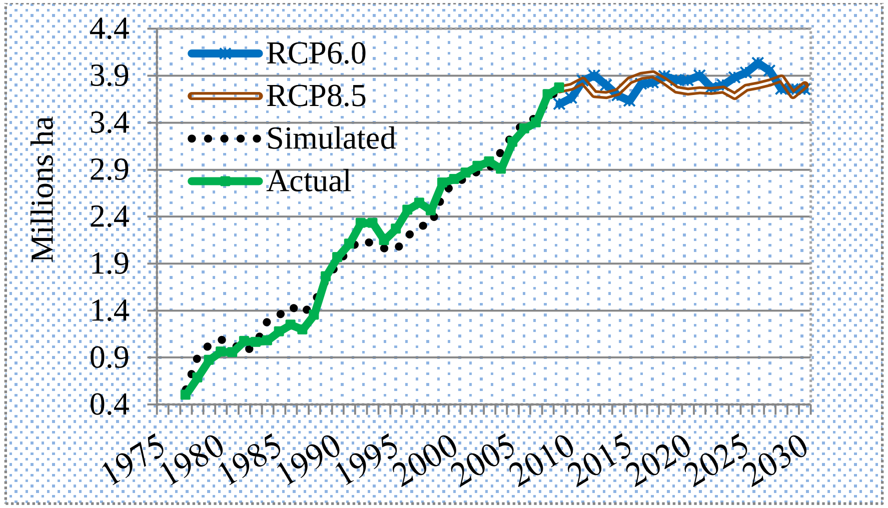

Figure 4.9. Forecast area of *Aman* modern variety

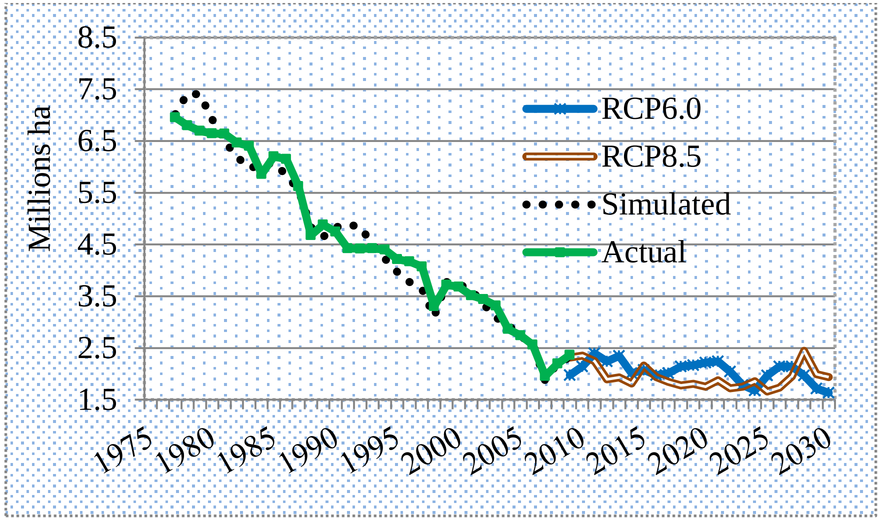

Figure 4.10. Forecast area of *Aman* local variety

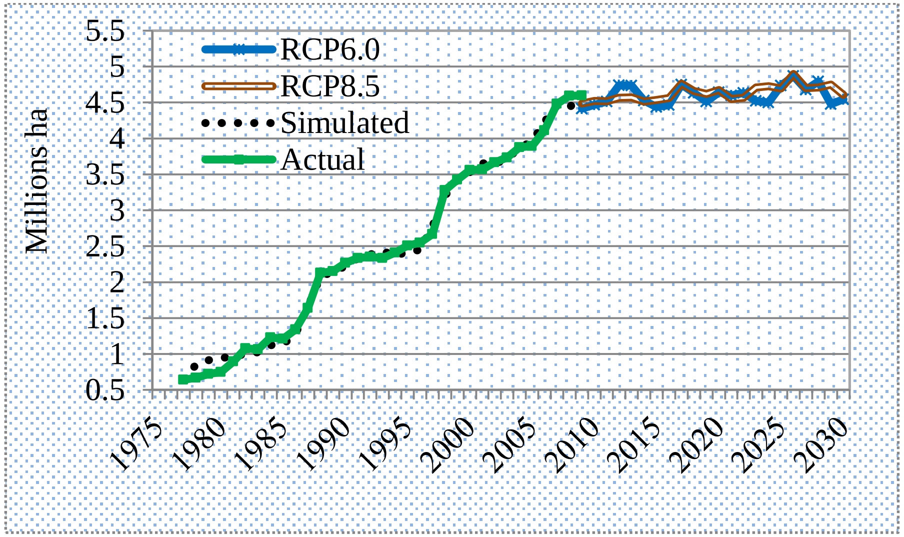

Figure 4.11. Forecast area of *Boro* modern variety

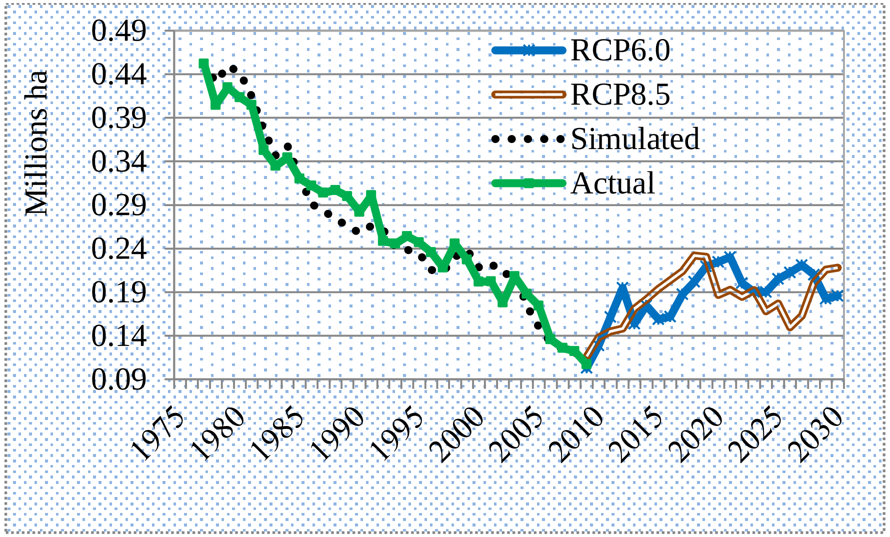

Figure 4.12. Forecast area of *Boro* local variety

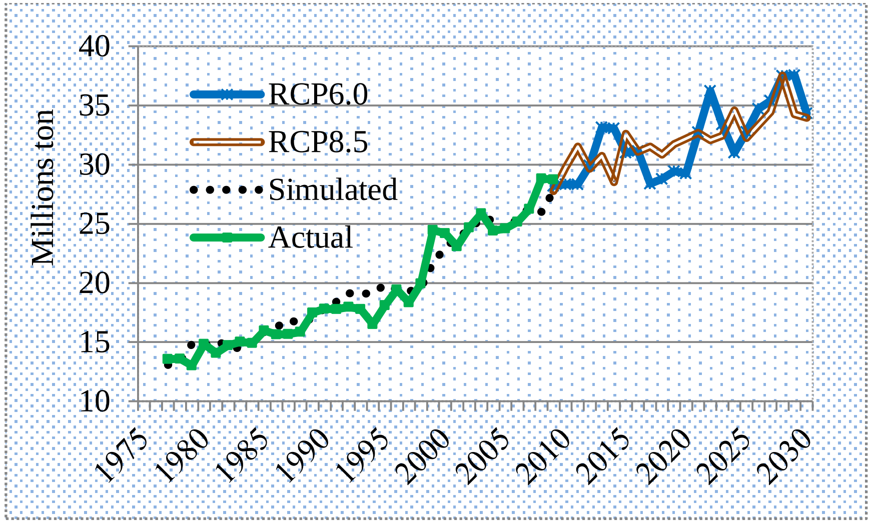

Figure 4.13. Forecast supply of rice variety

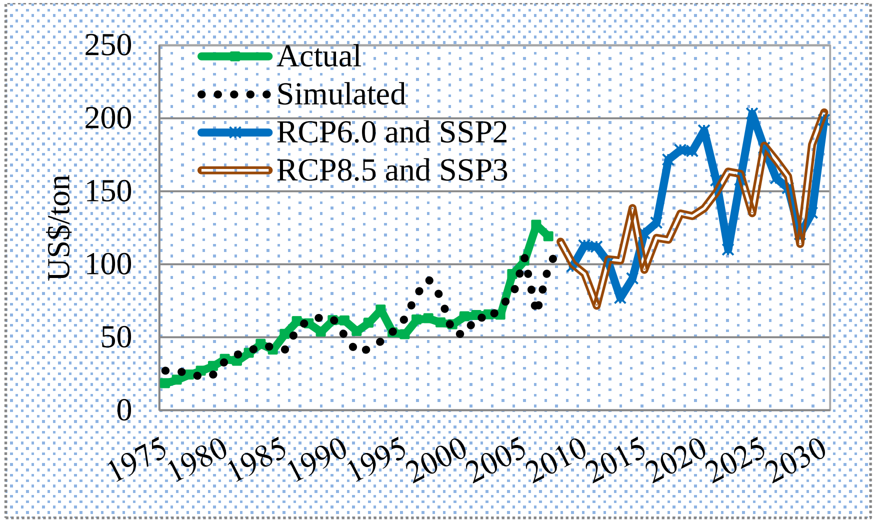

Figure 4.14. Forecast farm price of rice variety

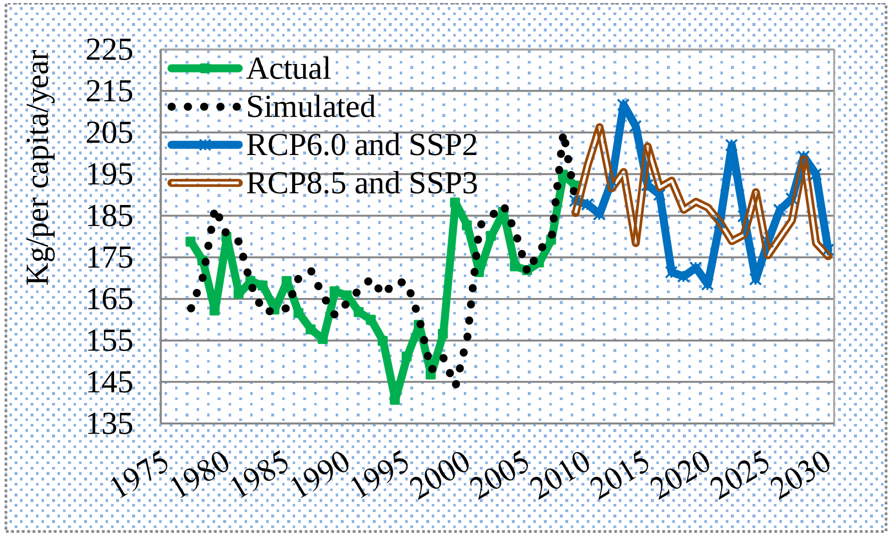

Figure 4.15. Forecast demand for rice variety

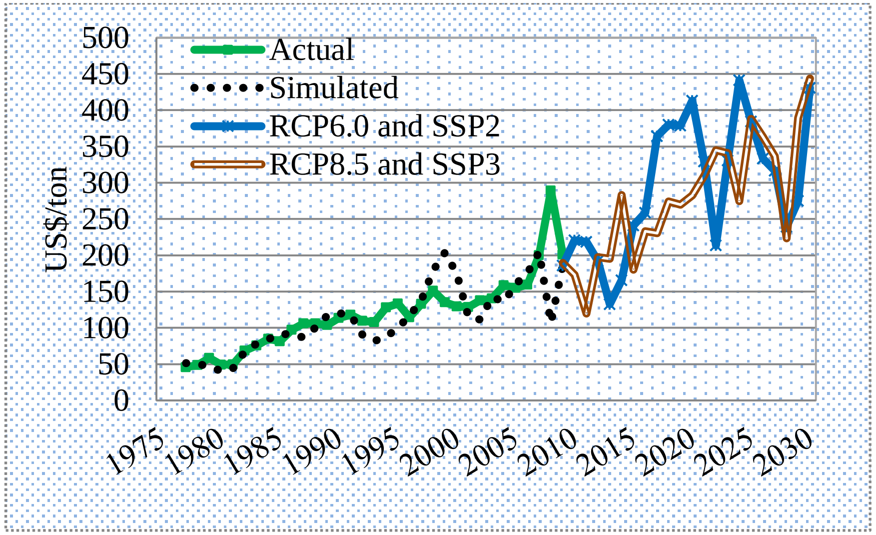

Figure 4.16. Forecast retail price of rice variety

4.3 Coefficient of Variation of Area, Yield, Market Price and Consumption

Simulation results on Co–efficient of Variation (CV) of yield, area, supply, price, and demand were given in the Tables 4.4–4.6. CV of modern *Aus* yield would be 9.3% in RCP6.0, which would be higher than in RCP8.5 (9.0%). CV of local *Aus* yield would be 9.9% in RCP8.5, which would be higher than RCP6.0 (9.7%) (Table 4.4). Fluctuations of rainfall in July and temperature in May were observed as slightly higher in RCP6.0 compared to RCP8.5, which would influence more variation of modern yield in RCP6.0. Fluctuation of rainfall in April was observed as slightly higher in RCP8.5 compared to RCP6.0, which would influence more variation of local *Aus* yield in RCP8.5. The climate variables in April and May would be very important for *Aus* crop because the crop would start panicle initiation in April and would start flowering in late May

Table 4.4 CV (%) of seasonal rice yield in 2010–2030

Seasonal yield	Yield variation (%)			
	RCP6.0		RCP8.5	
	Modern	Local	Modern	Local
Aus	9.3	9.7	9.0	9.9
Aman	8.7	8.2	7.9	6.1
Boro	14.7	13.6	9.5	10.8

Table 4.5 CV (%) of seasonal rice area in 2010–2030

Seasonal area	Area variation (%)			
	RCP6.0		RCP8.5	
	Modern	Local	Modern	Local
Aus	15.0	13.9	14.1	11.8
Aman	2.6	10.2	1.8	10.9
Boro	2.7	13.9	2.2	14.9

Table 4.6 CV (%) of supply, market price, and consumption in 2010–2030

Variables	Historical	Scenarios	
		RCP6.0 and SSP2	RCP8.5 and SSP3
Supply of rice	7.1	9.3	7.5
Farm price	21.5	25.5	24.2
Retail price	27.0	30.5	29.1
Consumption	4.5	6.5	4.5

CV of modern *Aman* yield would be 8.7% in RCP6.0, which would be higher than in RCP8.5 (7.9%). In addition, CV of local *Aman* yield in RCP6.0 (8.2%) would be higher than in RCP8.5 (6.1%). The results revealed that the yields of both *Aman* varieties would fluctuate more in RCP6.0 compared to RCP8.5 (Table 4.4). Fluctuations of temperature, rainfall, and solar radiation in October were observed as higher in RCP6.0 than in RCP8.5. The temperature in October would be observed to be very important because the *Aman* crop would start flowering in this month. In addition, modern *Aman* varieties would be relatively temperature resilient than that of local *Aman* but, for adaptation to future climate change, more temperature resilient varieties would be necessary.

CV of both *Boro* yields would be substantially higher in both RCP6.0 and RCP8.5 than in two other seasons, but the variation of both modern (14.7%) and local (13.6%) *Boro* yields would be found to be much higher in RCP6.0 than the modern (9.5%) and local (10.8%) *Boro* yields in RCP8.5. (Table 4.4). The simulation showed that high fluctuation of rainfall in March in both RCP6.0 and RCP8.5 (flowering stage) would influence the variation of yield in the *Boro* season. Therefore, ensuring irrigation facilities where there were no available water resources or no well–developed irrigation system during the flowering stage of *Boro* crops, were very important for stable rice production in future. Fluctuations of seasonal temperature and rainfall were found to have a significant influence on the instability of rice production. In remarks, the result of yield variation attributed to climate change was mostly nuanced with most result of the earlier studies on impact of climate change (Peng *et al*., 2010; Welch *et al*., 2010; Sheehy *et al*., 2005; Shah *et al*., 2011; Siddika, 2013; Kabir, 2015; Karim *et al.,* 1996.

The seasonal variation of planted area allocation to rice cultivation could be viewed in Table 4.5. Area variations by season and varieties were found to be higher in the scenarios of

RCP6.0 than in RCP8.5 which would illustrate the high impact of climate change under the assumption of RCP6.0 scenarios (Table 4.5).

High volatilities of per capita consumption and market price would be found in RCP6.0 and SSP2 as well as RCP8.5 and SSP3, fluctuation of consumption (4.5%), farm price (24.1%), and retail price (29.2%) would be relatively smaller in RCP8.5 and SSP3 than those in RCP6.0 and SSP2 (6.5%, 25.5%, and 30.5%) (Table 4.6). Fluctuation of supply would be also found to be relatively higher in RCP6.0 and SSP2 (9.3%) than that in both RCP8.5 and SSP3 (7.5%) and historical period (7.1%) (Table 4.6). The high volatility of price would negatively affect the consumption of low-income people and producer decision in the prediction period (Table 4.6).

CHAPTER–VI

COUNTER MEASURE FOR REDUCTION OF PRICE VARIATIONS

6.1 Importance of Counter Measures

The entire analysis in the earlier had discussed profoundly the effect of climate variables that caused substantial variations in rice production and market price. The variation in production due to climate change was also supported by Sarker *et al*. (2012); Siddika (2013). Several previous studies also supported more strongly that Bangladesh would continue to have a frightening experience of erratic climate, and fluctuation of production and price variation which had been regarded as major features of the food insecurity (Talukder, 2005; Dorosh *et al.,* 2002). To ensure smooth market functioning, the government of Bangladesh would have been induced with an attempt to control prices variation in domestic market through procurements (2–4% of production) and distributions (2–7% of demand) (Dorosh and Shahabuddin, 1999). The procurement would have likely been dedicated to boosting up producers' income through providing support price when market price drastically would go down. On the other hand, public distribution was undertaken to reduce high price effect on consumers' purchase of rice when price highly would go up. The mainstream of this chapter more meticulously dealt with policy adaptation in Bangladesh to reduce the projected fluctuation of market price that could be attributed to consequences of climate change. Therefore, this chapter aimed more to examine the potential effects of the food policy to mitigate the impact of climate change on price variation and also made more attempt to estimate consequent cost for reduction of rice price variation. For this purpose, the present study could have developed and integrated a rice policy regime into a rice supply and demand model in Bangladesh. Results of this study were expected to offer basic information for food policy makers in the era of climate change.

6.2 Calibration Scenarios Chosen for Counter Measure

RCP6.0 was selected for investigation of adaptation policies because this scenario could be characterized by the medium baseline mitigation stabilized at 6.0 W/m^2 (855ppm CO_2 eq) by the 2100 and the rapid economic growth. In addition, RCP6.0 would be led to result in 2–3.7°C increase of temperature by 2100 and this was recognized as a more representative scenario in Asia including Bangladesh. On the other hand, SSP2 showed the intermediate challenges in which growth of population and GDP scenarios would be operated very moderately and environmental sustainability was also given more emphasis. The combination of RCP6.0 and SSP2 had already been investigated to generate a substantial variation in the quantity of production and market price (see further Chapter–IV).

Table 6.1 Comparison of CV (%) of seasonal rice yield, 2010–2030

Seasonal	Yield variations (CV)		Effect of climate
	Historical	RCP6.0	
Aus	8.32	9.3	0.98
Aman	7.76	8.72	0.96
Boro	12.28	14.6	2.32

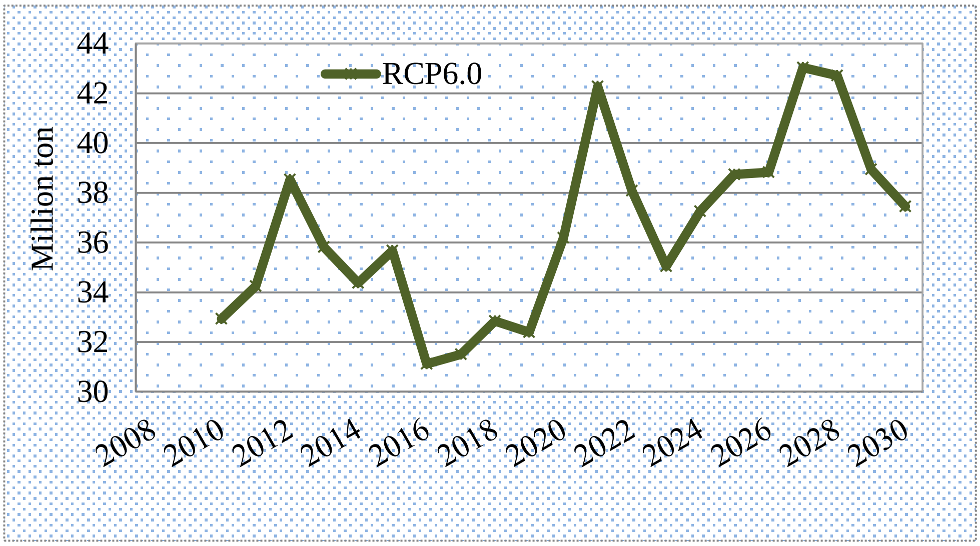

Figure 6.1 Fluctuation of rice production in period of 2010–2030

Furthermore, simulation results showed that the coefficients of variation (CV) of yields were higher under RCP6.0 scenario than in historical data. This implied greater impacts of climate variable on rice production in Bangladesh. To consider the aforementioned matter, RCP6.0 and SPP2 scenarios were selected for counter measure analysis (Table 6.1 and Figure 6.1).

Support price activities were conducted to reduce the losses when the farmers were usually exposed themselves to lower market prices and to refill the public storage from domestic rice sector. The policy was only considered for the special year when the price dropped below the line of average expected price. The feasible support price scenario was searched in the following way:

$$P_{GQRpolicy} = (1+\kappa_{GQR})P_{GQRbaseline} \quad (6.1)$$

where, $P_{GQRpolicy}$ was the support price with the special policy consideration; κ_{GQR} was the percentage increased by the policy concerns; and $P_{GQRbaseline}$ was the support at baseline scenario which could be defined as “Markup”.

Subsidized price should have been used considering the income of marginalized section of people. This policy should have also been undertaken only for the special year when the price soared up that might have created higher inability of households to purchase rice. In policy regulation, baseline scenario, which was obtained from model simulation under climate and socioeconomic scenarios of IPCC, was further committed to establishing the standard norm for the derivation of special policies. The feasible subsidized price was also searched in the following way:

$$P_{PDSpolicy} = (1-\kappa_{PDS})P_{PDSbaseline} \quad (6.2)$$

where, $P_{PDSpolicy}$ was the subsidized price with the special policy consideration; κ_{PDS} was the percentage reduced by the policy concerns; and $P_{PDSbaseline}$ was the subsidized at baseline which could be defined as “Markup”.

The baseline scenarios had been assumed for those variables which were exogenously determined beyond the policy control; even they had an indirect effect slightly on market price variations. To emphasize on a strong interest in the effect of GDP and world price on price variation, sensitivity analysis of both variables effect on domestic price variation had been performed and more extensive discussion was given below.

6.3 Sensitivity Analysis of World Price and GPD on Market Price during 2010–2030

The policy analysis was needed to confirm the effect of world price and GDP on the price variation, the sensitivity analysis on world price and GDP was carried out controlling all other variables in the supply and demand model. Both world rice price and per capita GDP were considered as target variables to conduct the sensitivity analysis on the variation of the retail price. The reason was that rice import and per capita GDP were exogenous variables which were regarded to have significant impacts on supply and demand of rice. The results (Table 6.2) showed that a 5% rise in world rice price would increase the retail price variation by 3.50 point, and a 5% decrease would reduce the variations by 4.55 point. On the other hand, a 5% rise in per capita GDP slightly would reduce the retail price variation by 0.12 point, and a 5% decrease would slightly increase the variations by 0.12 point. These results implied that world rice price would have a large impact on domestic rice price variation. Though it was not the main target of this study, in–depth study of the effect of import price on domestic food market would also be an important challenge for future.

Table 6.2 Sensitivity analysis on retail price variation

Shock type	Shock level 5% low	3% low	1% low	Baseline	1% high	3% high	5% high
WP	– 4.55	–1.55	–1.14	0	0.45	2.09	3.50
GDP	0.12	0.07	0.02	0	–0.02	–0.07	–0.12

Changes in coefficient of variation of retail price (%point) due to external shocks. WP= world rice price, GDP=gross domestic product per capita

6.4 Estimation of Public Import, Private Import, and Private Stock Change

Table 6.3 Parameters and elasticities of public and private import and private stock

	Intercept	Trend (1994=1)	Production (ΔQ_t)	Price ratio (WP_t/RPR_t)	Retail price (ΔRPR_t)	Dummy	$AdjR^2$ DW
Public Import	*** 712288 (3.09)	*** 119310 (4.78)	*** –0.14 (–3.55) [–0.86]	*** –1152347 (–3.46) [–8.65]		D956 D004 D067	0.82 2.70
Private Import	*** 2643443 (8.19)		*** –0.42 (–7.91) [–0.52]	*** –1680719 (–4.96) [–2.53]		D94 D96 D97 D99 D08	0.94 2.07
Private stock change	*** – 1554394 (–3.92)	** 101041 (2.16)	0.59 (2.92) [3.47]		–321* (–1.84) [0.2]	D970 D08 D09	0.86 2.48

****,**, * indicates significant at 1%, 5% and 10%
Value in ( ) was t–values and values in [ ] indicates elasticities

Parameters estimate and model criteria of public and private import and stock change were given in Table 6.3. Table 6.3 showed that change in rice production and the ratio of world price to retail price had an expected sign and generated the statistically significant result in both private and public import function. Similarly, the change in production and retail price were also statistically significant for price stock change. According to the Durbin–Watson (DW) value and $R-$square, all the estimated model had a criteria of good fitness.

6.5 Estimation of Public Procurement and Distribution

Ordinary least square (OLS) method was not applicable to estimate the parameters of procurement and distribution. The consideration was that procurement and distribution were subject to the constraints of the public stock level. For this reason, Tobit model, which could take into account of the upper limit of public stock, was applied to estimate the procurement and distribution functions. Moreover, in Bangladesh, storage capacity was less than or equal to 1.7 million ton for both rice and wheat. Domestic production of wheat dramatically decreased as winter becomes shorter. Public import of wheat was also very small in recent years. Annual procurement of food–grain was maximally coded at the upper limit U_t that was equal to 1.7 million ton. Moreover, a latent variable could be declared for truncated Tobit model of the procurement and distribution with the upper limit as follows:

$$GQPD_t^* = f_{pm}(GQPD_t \mid GQPD_t \geq U_t) = \begin{cases} GQPD_t if GQPD_t < U_t \\ U_t if GQPD_t \geq U_t \end{cases} \tag{6.3}$$

where, f_{pm} was indicated by the policy model (procurement and distribution). $GQPD_t^*$ was latent variable for the procurement GQR_t and PDS_t distribution, respectively. Therefore, Tobit model, which could take into account of truncation, was applied to estimate the parameters of the procurement and distribution functions.

With the public procurement and distribution activities, the government of Bangladesh could support farmer and consumers during price fall and shortfall of rice when the market price would soar up. The estimation results of procurement function indicated that procurement was more responsive to domestic production and support price with expected elasticities (Table 6.4), whereas public stock and subsidized price influenced supply in distribution function remarkably. Table 6.4 demonstrated that support price and the parameter (reaction intensity) of production and government stock were possible candidates of policy variables for supporting farmers. On the other hand, the subsidized price of rice and the parameter of government stock were candidates of policy variables in supporting consumers (Table 6.4).

Table 6.4 Parameter and elasticities of public procurement and distribution

	Intercept	variable	variable	variable	Dummy
		Q_t	$SFP–P_{GQRt}$	$PBES_{t–1}$	D944
Procurement	–1760401***	0.08***	136***	–0.53***	D06
	(–5.14)	(12.46)	(5.37)	(–4.42)	D07
		[2.262]	[1.02]	[–0.33]	D09
					D946
		ΔRPR	P_{PDSt}	$PBES_{t–1}$	D990
Public distribution	1607052***	23.33**	–129.96***	0.27***	D034
	(4.09)	(2.35)	(–34)	(2.49)	D07
		[0.002]	[–1.85]	[0.14]	D08

****,**, * indicates significant at 1%, 5% and 10%
Values in [ ] indicates elasticities and value in ( ) was t–values

Dummy variables, which were found to be statistically significant in the estimation, indicated special policies implementation and measure for external changes. The inclusion of dummy variables enhanced the estimation to produce statically significant parameters in the estimation of policy model (Appendix–A).

6.6 Selection of Policy Variables for Adaptation Options and Results

In pursuance to derive more concrete decision of policy variables, the authors estimated policy efficiency index (Table 6.5). To obtain the index, the elasticities of price variations or prices to candidates of policy variables (E_{GQR_P}, E_{PDS_P}) and the elasticities of the necessary budget to candidates of policy variables (E_{GQR_B}, E_{PDS_B}) were calculated by the following equations (as for an example):

$$E_{GQR\_P} = \left(\frac{V_{policy} - V_{base}}{V_{base}}\right) / \left(\frac{P_{GQR\_policy} - P_{GQR\_base}}{P_{GQR\_base}}\right) \tag{6.4}$$

$$E_{GQR\_B} = \left(\frac{FC_{policy} - FC_{base}}{FC_{base}}\right) / \left(\frac{P_{GQR\_policy} - P_{GQR\_base}}{P_{GQR\_base}}\right) \tag{6.5}$$

$$E_{PDS\_P} = \left(\frac{V_{policy} - V_{base}}{V_{base}}\right) / \left(\frac{P_{PDS\_policy} - P_{PDS\_base}}{P_{PDS\_base}}\right) \tag{6.6}$$

$$E_{PDS\_B} = \left(\frac{FC_{policy} - FC_{base}}{FC_{base}}\right) / \left(\frac{P_{PDS\_policy} - P_{PDS\_base}}{P_{PDS\_base}}\right) \tag{6.7}$$

where, the subscript policy meant variables with policy, subscript base meant variables without policy, V was the coefficient of variation of price, support price P_{GQR} and subsidized price P_{PDS} which were candidates of policy variable, and FC was the necessary budget for public food operation. Policy efficiency index could be derived from the equation (6.4–6.7) in the following form:

$$E_{GQR\_PB} = \frac{E_{GQR\_P}}{E_{GQR\_B}} \tag{6.8}$$

$$E_{PDS\_PB} = \frac{E_{PDS\_P}}{E_{PDS\_B}} \tag{6.9}$$

where, E_{GQR_PB} and E_{PDS_BP} were the policy efficiency index. E_{GQR_PB} and E_{PDS_BP} were the calculated policy index that indicates one unit of the public budget could reduce what magnitude of price variation and control what level of market price movement.

According to Table 6.5, the support price was the most efficient for farmer support, and the subsidized price was the most efficient for consumer support. Efficiency index showed that support price could reduce more price variation of both farm and retail price while it could increase farmers' income than any other candidate variables. Similarly, subsidized price could reduce more price variation of retail price than any other candidate variables. Finally, the author adopted the support price and subsidized price as policy variables.

Table 6.5 Policy efficiency index

	Variation index		Price index	
Procurement	Farm price	Retail price	Farm price	Retail price
Production	–0.05	–0.014	0.014	0.01
Support price	–0.28	–0.20	0.017	–0.028
Beginning stock	–0.07	–0.04	0.016	0.011
Distribution				
Price	0.47	0.54	0.094	0.093
Subsidized price	–0.50	–0.50	–0.01	–0.02
Beginning stock	–0.43	0.033	–0.00	–0.013

With regard to examining the effects of the policies on the price variations, the author could set more practical policy criteria where if a price level was 10% higher or lower than a linear approximated trend line; the government should have taken a special policy. The price bands (upper and lower boundaries) as policy criteria were shown in Figure 6.2–6.5. Red line was upper price band and 10% higher than the approximated trend of baseline price. Green line was the bottom border of price band and 10% lower than the approximated trend of baseline price (black line). Price band, shedding light on different adopted ranges, was consistently nuanced with the empirical approaches used by many economists (Ahmed and Bernard, 1989, Ahemd *et al*. 1993; Goletti, 1991; Islam and Thomas, 1996).

6.7 Alternative Policy Investigation

With a view to comparing the effect of special policy implementation, at the first, the author had accomplished the analysis of the baseline market mechanism combined with imports and private stock change under the climate effect. After that was completed, the analysis was proceeded to apply the special price policies for the price hike and the price fall to mitigate the higher price variations found in the baseline. In essence, according to the result of baseline, the most of the attempt were dedicated to derive the special prices policies and to bring the benefits in favour of both producers and consumers. Therefore, the baseline was provided as counterfactual to compare the results which were calibrated under the alternatives adaptation policies scenarios. The baseline of simulated market price was denoted by the pink line in figures 6.4 to 6.5. The dotted line appeared from the implementation of the alternative price policies in order to mitigate the price variation in the course of climate change.

As the special policies, the author had applied on an average 60% higher support price from the baseline to recover the drastic price fall occurred in 2013, 2022, 2028 and 2029. A 75% more subsidy for rice distribution was also applied to mitigate extreme price rise in 2018, 2019, 2020, and 2024 in favour of the consumers.

To examine the effects of both policies respectively, the author assumed the policies separately for future projections. As Figure 6.2 showed, sharp price falls were mitigated by the extended support price in favour of farmers. However, price hikes were not significantly affected. The consequent reduction in variation (CV) was 1.49% and its additional policy budget was US$151 million. On the other hand, as Figure 6.3 showed, the extended subsidized price for distribution could mitigate price hikes in favour of consumers, but it did not significantly affect price falls. The consequent reduction in variation (CV) was 1.38% and necessary policy budget would be US$79 million. These results implied that to mitigate both price hikes and falls due to climate change, the dual policy including support price and subsidized price was far more necessary.

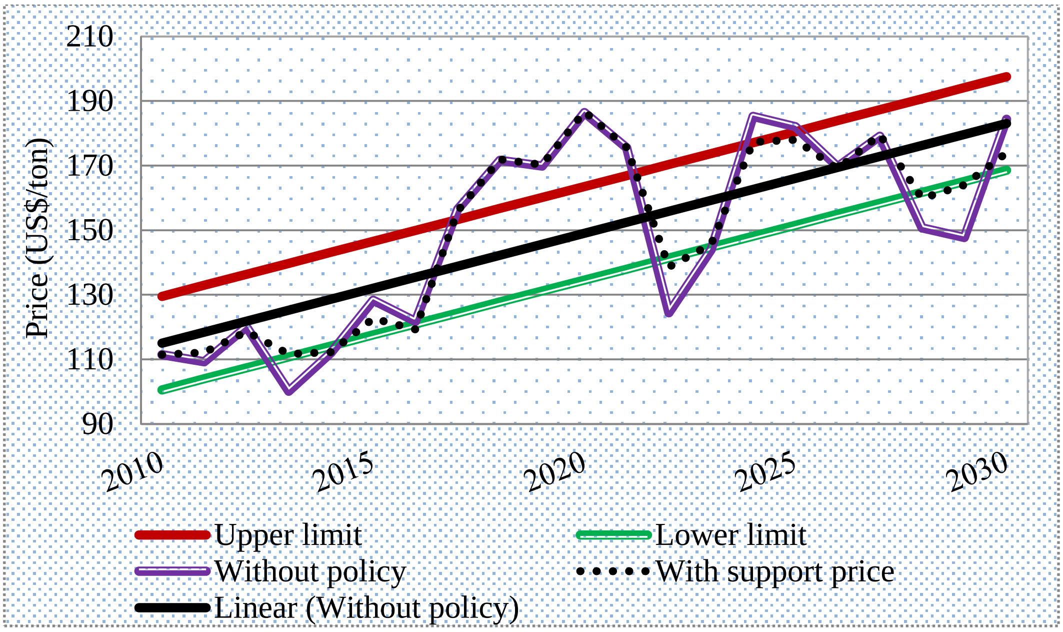

Figure 6.2 Farm price under support price policy

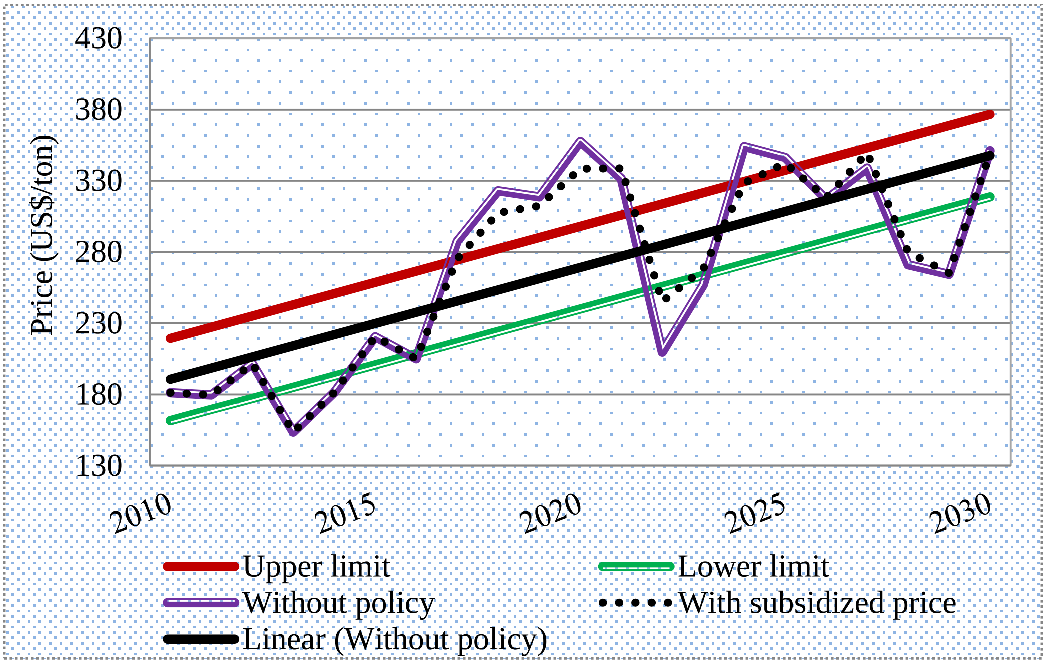

Figure 6.3 Retail price under subsidized price policy

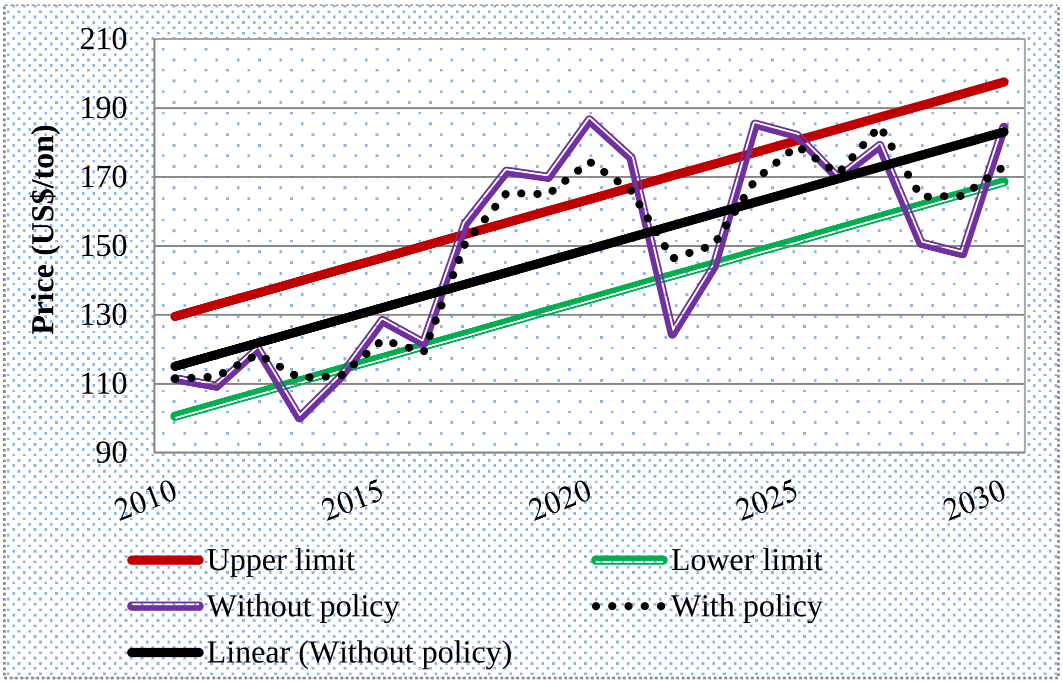

Figure 6.4 Farm price under dual price policy

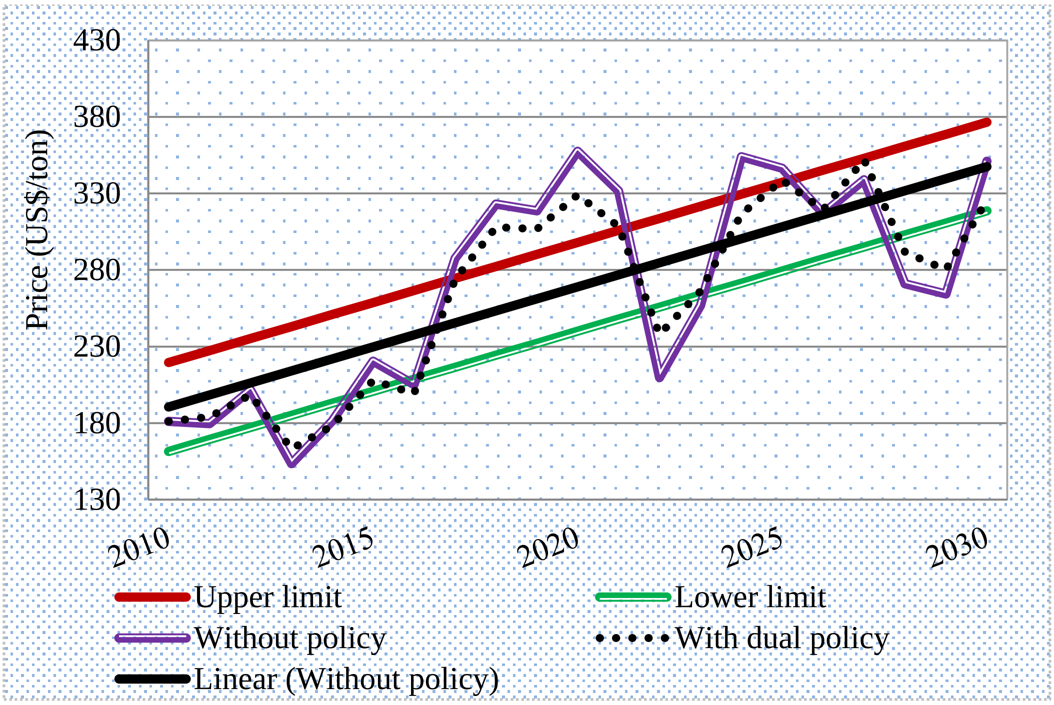

Figure 6.5 Retail price under dual price policy

As Figure 6.4 and 6.5 showed, both the price hikes and the falls had a tendency to be mitigated by the dual policy. Projection results also showed that the variation (CV) of farmer's price and the retail price could be reduced with the dual price policy compared to CV in the baseline (Table 6.6). The simulation further revealed that the reduction of 1% price variation would cost US$78 million per year with the dual policy in the projection period. Policy limitation for unlimited reduction of price hikes implied here that higher degree of constant price hikes could not be mitigated with the limited policy operation. Adaptation policy for reduction of price variation might be conducted by the limited public stock. Accumulating stock did indefinitely not go beyond the array of storage capacity and limited allocation for investments, most possibly because the policies operation had been undertaken within high physical constraint and fiscal constraint (Goletti et al. 1991).

Table 6.6 Reduction of price variation with dual policy

Price	Variation (%)		Effect
	Without policy	With Policy	
Farm price	19.89	17.50	–2.35
Retail price	25.75	23.42	–2.33

Furthermore, the findings from the projections included necessary storage capacity. In accordance with increasing variation of rice production, the government had at least to procure an average of nearly 1.6 million ton additional/excess market supply of rice per year during the projection period 2010–2030, to mitigate price below the price band. The distribution would increase to an average of 2 million tons of rice per year to push down from the upper price band. Subsequently, the increased procurement and distribution requires the extension of government storage capacity to 3 million ton from present capacity, 1.7 million ton.

CHAPTER–VIII
CONCLUSIONS AND RECOMMENDATIONS

This study was conducted to predict the variation of rice production and the market price so as to deal with the future food security challenges. In order to fulfill the formulated objectives, yield, acreage, stock change, import, and demand functions were constructed to evaluate the effect of climate and socioeconomic changes on future food supply and trend of demand under AR5 (RCP6.0 and RCP8.5) and SSPs (SSP2 and SPP3) of Intergovernmental Panel on Climate Change (IPCC).

To develop yield function, climate variable was thought to be the major determinants; yield function incorporated climatic variables (rainfall, temperature, and solar radiation) and time trends which were used for technological progress (improved cultivars, all kind of machinery and fertilizers). In addition, rice yield in Bangladesh had a long–term increasing trend, which illustrated constant dissemination of modern crop technologies and had been supported by government and NGOs to boost up productivity. The variation in yield caused by climate factors was substantially higher than variation in yield (minimal) which was attributed to farmers' decision. All yield functions were estimated using OLS method and independent variables in the functions were found to be statistically significant at the different level of significance. In econometric estimation, the adjusted R-square ranged from 0.85–0.93 and Durbin–Watson for first order autocorrelation statistics ranged from 1.9–2.18. Accordingly, all models were econometrically good fit and there had no serial autocorrelation in the model. Technological advancement had a positive role on upward trending of yield in all seasons by varieties and justifies the effort of high research investment and rapid extensions of the modern technology at farmers' hand (Table 4.1).

In Bangladesh, there was data limitation of specified planted area. In national statistics, the harvested area was considered as planted area. The planted area (harvested area) functions of three seasons were specified as a linear function based on the adaptive expectation model. The explanatory variables were time trend, one year lagged planted area and farm price, and one year lagged rainfall for *Aman*, one and two–years lagged rainfall for both *Aus* and *Boro* seasons. Most of the variables in the area functions showed statistical significance in the model estimation. In econometric estimation, the adjusted R-square ranged from 0.93–0.98 and Durbin–Watson H statistics ranged from 1.95–2.5. Therefore, all models were econometrically good fit and there had no more serial autocorrelation in the model (Table 4.2).

Furthermore, the estimated parameter of rice price, according to microeconomics, follows the sign condition between quantity demand and market prices and own market price. Rice is staple dish and the main source of calorie intake in Bangladesh. Own price elasticity of rice had an inelastic effect on rice demand goods because the value of price elasticity (–0.48) was found less than one. According to Varian (2003), the absolute value of elasticity, which ranges usually between zero and one, is defined as inelastic good. The estimates showed that a 10% increase in rice price would reduce 4.8% of rice consumption. On the other hand, wheat is a major substitute to rice. The substitute elasticity of wheat price indicated that a 10% rise in wheat price would, most possibly, would lead to 2.3% of rice consumptions. Even though the income per capita was not strongly significant, the negative sign of the elasticity (–0.13) indicated that with an increase in income, demand for rice would be indicated by inferior good (Varian, 2003). More recently, GDP growth in Bangladesh is absolutely in rising trend and rising income per capita encourages households to reshuffle the lists of daily consumption items. This, more likely, means that demand for non–cereal such as fish, meat, and egg tends to increase in rapid trend (Murshid et al. 2008). Likewise, stock change function and import function showed a consistent result with a prior expectation. The price linkage function was, similar to the notions, delved that upstream transmission of rice price flow (i.e. retail price) would likely determine the trajectory of farm price movement (Table 4.3).

In the succedent part, simulation had been carried through major assumptions–such as the linear trend of yield functions were continued which had been termed as the technological progress imputing to upward trend of average yield; the trend applied in area functions remained flat for the given period; each climate scenario was regarded to have its own attribute of fluctuation and that which affected the trend of the supply and the determination of market price; finally the estimated parameters were assumed to be fixed. The simulation of supply and demand system model had been ended up with the iterative calibration.

The simulated results demonstrated that fluctuations of rainfall in July and temperature in May would be higher in RCP6.0 compared to RCP8.5, which would influence more variation of modern *Aus* yield in RCP6.0. Fluctuation of rainfall in April would be higher in RCP8.5 compared to RCP6.0, which was a source of more variation of local *Aus* yield in RCP8.5.

Fluctuations of temperature, rainfall, and solar radiation in October would be higher in RCP6.0 than in RCP8.5. The temperature in October was important because the *Aman* crop would start flowering in this month. In addition, modern *Aman* varieties would be relatively tolerant to temperature shock than that of local *Aman* but, for adaptation to higher temperature in future climate change, more temperature resilient varieties might be a great concern and should have been given the higher priority in the era of climate change.

The simulation further showed that high fluctuation of rainfall in March in both RCP6.0 and RCP8.5 (flowering stage) would influence the variation of yield in the *Boro* season. Therefore, ensuring irrigation facilities should be given an emphasis where there are no available water resources or no well–developed irrigation system during the flowering stage of *Boro* crops is be very important for stable rice production in future.

Based on the simulation, the result could be concluded that fluctuations in seasonal temperature and rainfall were found to have a significant influence on the variation of rice production in both RCP6.0 and RCP8.5. Moreover, yield variations in the two major seasons (*Aman* and *Boro*) would be higher in RCP6.0 than RCP8.5. Despite increasing volatility, the variation of consumption and market price were found in all scenarios. Per capita consumption, farm price, and retail price would be relatively stable in RCP8.5 and SSP3 than in RCP6.0 and SSP2 (Table 4.4–4.6).

In summary, the result revealed that the governments of Bangladesh should allocate a good research budget to concentrate on the development of temperature-resilient *Aman* cultivars and develop irrigation facilities where well-developed irrigation facilities are not yet available in *Boro* season. At the same time, a price–stability measure based on future production is required for price stability in favour of both producers and poor consumers in order to meet future challenges of the food security.

Stochastic simulation in model system variation of production would expand to 7.85 million metric tons between 90th and 10th percentile and the percentage change would extend, relative to production in the baseline (7.9%), was 11.0% and 10.5%, respectively (Figure 5.10). Therefore yield and rice production would be very sensitive to erratic manners of climate variables.

Furthermore, the farm price and retail in the stochastic path were investigated. The simulation result indicated that a spread of fluctuation in both farm and retail price would be getting larger than that would occur in the historical period. The difference between 90th and 10th percentile for farm price would be US$ 63.21 per metric ton while this for the retail price would be US$ 139.07 per metric ton (Figures 5.11–5.12).

To measure the effect and cost of the policy to mitigate rice price fluctuation, the author conducted future projections under the scenario combining IPCC climate RCP6.0 (medium intensity) and socioeconomic SSP2 (intermediate challenges) scenarios, with 2010 to 2030 for projection period. Based on the policy criteria, the author adopted the support price and subsidized price as policy variables (Table 6.5). To examine the effects of the policies on the price variations, first, a more practical policy criterion was also chosen where if a price level was 10% higher or lower than a linear approximated trend line; the government should have made a special policy (Figures 6.2–6.5).

A sharp price fall could be likely reduced by the extended support price in favour of farmers. However, price hikes were not significantly affected. The consequent reduction (CV) was 1.49 to price variation and its additional policy budget was US$151 million (Figure 6.2). The extended subsidized price for distribution could reduce price hikes in favour of consumers, but it did not significantly affect price falls. The consequent reduction in variation (CV) was 1.38 and necessary policy budget will be US$79 million (Figure 6.3).

To mitigate both price hikes and falls due to climate change, the dual policy including support price and subsidized price was far more important. Both resulting price hikes and falls could be mitigated to a considerable degree by the dual policy (Figure 6.4 and 6.5). Furthermore, the simulation showed that the reduction of 1% price variation would cost US$78 million per year with the dual policy in the projection period (Table 6.6).

The simulation also highlighted on the expansion of storage capacity. In consist with increasing variation of rice production and market price, the government should consider increasing procurement to an average of nearly 1.6 million metric ton during bumper harvest in the period 2010–2030, to mitigate price fall. The distribution will be required to increase by an average of 2 million metric tons of rice per year. The consequent increase in procurement and distribution will require the expansion of public storage capacity by 3 million metric ton from present capacity of 1.7 million ton.

These projected costs and budget effects were expected to be used as counterfactual data for food policy actions in the era of climate change. In addition, they could be used as a benchmark for assessment of various adaptation measures. Then, challenging tasks, which would be left in the following step, was the assessment of change in social welfare that happened because the adaptation policy, as counter strategies to eliminate the consequence of climate shock, would be implemented.

Next, chapter–VII focused on the effects of the implementation of the adaptation policy in an attempt to reduce the variation in the price of rice due to climate change and to measure the welfare effect in terms of net change in producer and consumer surpluses. The policy framework and surplus measure were combined into supply and demand model in order to evaluate the effect of adaptation policy. The effects of the adaptation price policies were examined as special policies pertaining to producer and consumer welfare, and the simulation found that implementing the support price policy would create a positive change in producer surplus of US$ 1,981 million, which was substantially higher than the consumer surplus (US$-1,785 million) in the intervened years (Figure 7.1).

Furthermore, the result showed that if the subsidized price policy was implemented, the price variation by 1.38% could be reduced and the change in consumer surplus (US$ 1,501 million) obtained in the intervened years. In contrary, producers would be worse off by US$-724 million (Figure 7.2). Nonetheless, to implement this adaptation policy would require a considerably higher amount of additional public stock (1.50 million metric tons) as well, which was considered to be one of its biggest limitations.

In order to search far more feasible policy, once the dual price policy was integrated into the simulation, on an average price variation by 2.34 percent could be mitigated and surplus change was estimated to be US$ 5,523 million as substantially higher than that possible through the implementation of each policy, separately (Figure 7.3). All type of policy scenarios resulted in a negative net change in social welfare million (US$) because of higher policy cost of transaction and warehouse construction including operation. Even though the negative net social welfare as well as a persistent difference in the magnitude of the surpluses was noticed, the dual policy significantly would boost up the positive change in surplus for both producers and consumers in the era of climate change.

To adapt the unavoidable climate change and eliminate the number of victims of food insecurity, public food policy is necessary even if the result of food policy is costly and ineffective (Dorosh *et al*., 2001a; Dorosh and Shahabuddin, 1999). These policies are expected to be a more suitable alternative adaptation, along with other recommended adaptation policies and those should be implemented, which helps sustain a stable food market in the era of climate change.

APPENDIX –A

SPECIFICATION OF THE ESTIMATED EQUATIONS

3.4.1 Yield function (Equation (3.3)):

i) Yield function of modern *Aus*

$$YR_{AuM} = \underset{(6.74)}{6.32} + \underset{(12.18)}{0.06^{*}T94} \underset{(-4.92)}{-0.09^{*}Tmp05} \underset{(-1.64)}{-0.04^{*}Tmp06} \underset{(-2.62)}{-0.0004^{*}Rf05} \underset{(-2.40)}{-0.0003^{*}Rf07} \underset{(-1.89)}{-0.096^{*}D079}$$

$AdjR^2$ AdjR^2 = 0.88 DW = 1.77

YR_{AuM}	Yield of modern *Aus*
$T94$	Time trend from 1994 to 2009
$Tmp05$	Temperature in May
$Tmp06$	Temperature in June
$Rf05$	Temperature in May
$Rf07$	Temperature in May
$D079$	Dummy, 1 in 2007 to 2009, 0 otherwise
$AdjR^2$	Adjusted R^2
DW	Durbin Watson value for serial autocorrelation

Value in parenthesis indicate $t-$value

ii) Yield function of local *Aus*

$$YR_{AuL} = \underset{(3.68)}{2.07} + \underset{(15.26)}{0.017^{*}TREND} - \underset{(-3.39)}{0.002^{*}Rf03} + \underset{(2.75)}{0.0005^{*}Rf04} - \underset{(-3.18)}{0.004^{*}Sr03} + \underset{(1.66)}{0.001^{*}Sr05} + \underset{(2.35)}{0.07^{*}D781} - \underset{(-4.46)}{0.125^{*}D958}$$

$AdjR^2$ AdjR^2 = 0.91 DW = 2.18

YR_{AuL}	Yield of local *Aus*
$TREND$	Time trend from 1977 to 2009
$Rf03$	Rainfall in March
$Rf04$	Rainfall in April
$Sr03$	Solar radiation in March
$Sr05$	Solar radiation in March
$D781$	Dummy, 1 in 1978 to 1981, 0 otherwise
$D958$	Dummy, 1 in 1995 to 1998, 0 otherwise

iii) Yield function of modern *Aman*

$$YR_{AuM} = 8.84 + 0.02*TREND - 0.165*Tmp06 - 0.09*Tmp10 + 0.003*Sr07 - 0.003*Sr10$$
(7.73) (10.84) (–6.58) (-3.76) (4.43) (–2.64)

$$+ 0.21*D770 + 0.28*D87 - 0.21*D97 + 0.27*SHIFT07$$
(4.67) (3.94) (–2.81) (3.48)

$AdjR^2$ AdjR^2 = 0.89 DW = 1.65

YR_{AmM}	Yield of modern *Aman*
$TREND$	Time trend from 1977 to 2009
$Tmp06$	Temperature in June
$Tmp10$	Temperature in October
$Sr07$	Solar radiation in July
$Sr10$	Solar radiation in October
$D770$	Dummy, 1 in 1977 to 1980, 0 otherwise
$D87$	Dummy, 1 in 1987, 0 otherwise
$D97$	Dummy, 1 in 1997, 0 otherwise
$SHIFT07$	Dummy, 1 after 2007, 0 otherwise

iv). Yield function of local *Aman*

$$YR_{AmL} = 4.23 + 0.011*TREND - 0.033*Tmp06 - 0.101*Tmp07 + 0.0003*Rf10 + 0.002*Sr07$$
(3.98) (10.02) (–1.89) (–2.95) (2.81) (3.05)

$$- 0.18*D978 - 0.128*D04 - 0.196*D07 + 0.112*SHIFT09$$
(–4.83) (–1.97) (–3.50) (1.73)

$AdjR^2$ AdjR^2 = 0.86 DW = 2.18

YR_{AmL}	Yield of local *Aman Boro*
$TREND$	Time trend from 1977 to 2009
$Tmp06$	Temperature in June
$Tmp07$	Temperature in July
$Rf10$	Rainfall in October
$Sr07$	Solar radiation in July
$D978$	Dummy, 1 in 1997 to 1998, 0 otherwise
$D04$	Dummy, 1 in 2004, 0 otherwise
$D07$	Dummy, 1 in 2007, 0 otherwise
$SHIFT09$	Dummy, 1 after 2009, 0 otherwise

v) Yield function of modern *Boro* rice

$$YR_{BoM} = 7.97 - 0.004^{*} Rf03 + 0.002^{*} Rf04 - 0.018^{*} Sr01 - 0.003^{*} D790 + 0.33^{*} D823$$
(7.35) (–3.22) (3.97) (-2.54) (4.51) (3.54)

$$+ 0.33^{*} SHIFT07$$
(3.69)

$AdjR^2$ AdjR^2 = 0.93 DW = 1.60

YR_{BoM}	Yield of modern *Boro*
$Rf03$	Rainfall in March
$Rf04$	Rainfall in April
$Sr01$	Solar radiation in January
$D790$	Dummy, 1 in 1979 to 1980, 0 otherwise
$D823$	Dummy, 1 in 1982 to 1983, 0 otherwise
$SHIFT07$	Dummy, 1 after 2007, 0 otherwise

vi) Yield function of local *Boro* rice

$$YR_{BoL} = -4.61 + 0.02^{*} TREND + 0.14^{*} Tmp06 + 0.07^{*} Tmp11\_1 + 0.28^{*} D834 - 0.18^{*} D889$$
(–4.06) (9.53) (3.42) (2.14) (2.81) (3.05)

$$+ 0.30^{*} D03$$
(2.82)

$AdjR^2$ AdjR^2 = 0.85 DW = 1.90

YR_{BoL}	Yield of local *Boro*
$TREND$	Time trend from 1977 to 2009
$Tmp06$	Temperature in June
$Tmp11\_1$	Lagged temperature in November
$D834$	Dummy, 1 in 1983 to 1984, 0 otherwise
$D889$	Dummy, 1 in 1988 to 1989, 0 otherwise
$D03$	Dummy, 1 in 2003, 0 otherwise

3.4.2 Area Functions (Equation (3.4)):

i) Area function of modern *Aus* rice

$$AR_{AuM} = -1215916 + 0.70^{*} AR_{AuM(t-1)} + 6.6^{*} SFP/(GDPD/100)_{t-1} - 1090.7^{*} Rf11\_2$$
$$\quad (-5.89) \qquad (12.56) \qquad (2.70) \qquad (-5.14)$$
$$- 100132^{*} D89 + 92285^{*} D97 + 61387^{*} D05 + 112789^{*} D078$$
$$\quad (-4.85) \qquad (3.75) \qquad (2.93) \qquad (7.52)$$

$AdjR^2 = 0.93$ $\quad DW = 2.37$

AR_{AuM}	Area of modern *Aus*
$AR_{AuM(t-1)}$	Lagged Area of modern *Aus*
$SFP/(GDPD/100)_{t-1}$	Realized of lagged farm price of rice
$Rf11\_2$	Two years lagged of rainfall in November
$D89$	Dummy, 1 in 1989, 0 otherwise
$D97$	Dummy, 1 in 1997, 0 otherwise
$D05$	Dummy, 1 in 2005, 0 otherwise
$D078$	Dummy, 1 in 2007 to 2008, 0 otherwise

ii) Area function of local *Aus* rice

$$AR_{AuL} = 1705528 - 28372^{*} TREND + 0.31^{*} AR_{AuL(t-1)} + 27.3^{*} SFP/(GDPD/100)_{t-1}$$
$$\quad (3.27) \qquad (-3.25) \qquad (1.76) \qquad (2.18)$$
$$+ 334^{*} Rf04\_1 - 222^{*} Rf05\_1 - 121553^{*} D89 + 110234^{*} D94 + 78781^{*} D963$$
$$\quad (2.09) \qquad (-2.11) \qquad (-1.83) \qquad (1.97) \qquad (2.93)$$

$AdjR^2 = 0.99$ $\quad DW = 1.79$

AR_{AuL}	Area of local *Aus*
$TREND$	Time trend from 1977 to 2009
$AR_{AuL(t-1)}$	Lagged Area of local *Aus*
$SFP/(GDPD/100)_{t-1}$	Realized of lagged farm price of rice
$Rf04\_1$	Lagged of rainfall in April
$Rf05\_1$	Lagged of rainfall in May
$D89$	Dummy, 1 in 1989, 0 otherwise
$D94$	Dummy, 1 in 1994, 0 otherwise
$D963$	Dummy, 1 in 1996 to 2003, 0 otherwise

iii) Area function of modern *Aman* rice

$$AR_{AmM} = -395929 + 301.9*TREND + 0.74*AR_{AmM(t-1)} + 51.4*SFP/(GDPD/100)_{t-1}$$
(–1.66) (2.22) (5.42) (2.32)

$$+515*Rf10\_1 - 1654*Rf11\_1 - 261813*D87$$
(2.25) (1.70) (–2.43)

$AdjR^2 = 0.99$ $DW = 2.14$

AR_{AuM}	Area of modern *Aman*
$TREND$	Time trend from 1977 to 2009
$AR_{AmM(t-1)}$	Lagged Area of modern *Aman*
$SFP/(GDPD/100)_{t-1}$	Realized of lagged farm price of rice
$Rf10\_1$	Lagged of rainfall in October
$Rf11\_1$	Lagged of rainfall in November
$D87$	Dummy, 1 in 1987, 0 otherwise

iv) Area function of local *Aman* rice

$$AR_{AmL} = 1502198 - 43769*TREND + 0.59*AR_{AmL(t-1)} + 109.9*SFP/(GDPD/100)_{t-1}$$
(1.13) (–1.68) (4.14) (2.14)

$$+ 915*Rf05\_1 - 457416*D889 - 435026*D98 + 373467*D99 - 759283*D07$$
(2.28) (–3.38) (–2.28) (1.88) (–3.80)

$AdjR^2 = 0.99$ $DW = 2.14$

AR_{AmL}	Area of local *Aus*
$TREND$	Time trend from 1977 to 2009
$AR_{AmL(t-1)}$	Lagged Area of local *Aus*
$SFP/(GDPD/100)_{t-1}$	Realized of lagged farm price of rice
$Rf05\_1$	Lagged of rainfall in May
$D889$	Dummy, 1 in 1988 to 1989, 0 otherwise
$D98$	Dummy, 1 in 1998, 0 otherwise
$D99$	Dummy, 1 in 1999, 0 otherwise
$D07$	Dummy, 1 in 1999, 0 otherwise

v) Area function of modern *Boro* rice

$$AR_{BoM} = -449048 + 36034*TREND + 0.73*AR_{BoM(t-1)} + 36.3*SFP/(GDPD/100)_{t-1}$$

(–1.91) (2.42) (6.86) (1.57)

$$+ 336*Rf08\_2 + 900*Rf10\_2 - 298687*D85 + 283402*D878 + 257233*D979$$

(2.03) (4.05) (–2.94) (4.06) (3.90)

$$+ 181471*D04$$

(1.80)

$AdjR^2 = 0.99$ $DW = 2.50$

AR_{BoM}	Area of modern *Boro*
$TREND$	Time trend from 1977 to 2009
$AR_{BoM(t-1)}$	Lagged Area of modern *Boro*
$SFP/(GDPD/100)_{t-1}$	Realized of lagged farm price of rice
$Rf08\_2$	Two years lagged of rainfall in August
$Rf10\_2$	Two years lagged of rainfall in October
$D85$	Dummy, 1 in 1985, 0 otherwise
$D878$	Dummy, 1 in 1987 to 1988, 0 otherwise
$D979$	Dummy, 1 in 1997 to 199, 0 otherwise
$D04$	Dummy, 1 in 2004, 0 otherwise

vi) Area function of local *Boro* rice

$$AR_{BoL} = 327187 + 0.68*AR_{BoL(t-1)} + 4.34*SFP/(GDPD/100)_{t-1} - 2113*Rf01\_1$$

(3.30) (9.26) (1.42) (–1.82)

$$+ 145220*D77 + 47641*D791 + 35188*D84 - 35779*D049$$

(9.05) (4.02) (2.28) (–3.94)

$AdjR^2 = 0.99$ $DW = 2.14$

AR_{BoL}	Area of local *Boro*
$AR_{BoL(t-1)}$	Lagged Area of local *Boro*
$SFP/(GDPD/100)_{t-1}$	Realized of lagged farm price of rice
$Rf01\_1$	Lagged of rainfall in January
$D77$	Dummy, 1 in 1977 to 1989, 0 otherwise
$D791$	Dummy, 1 in 1979 to 1981, 0 otherwise
$D84$	Dummy, 1 in 1984, 0 otherwise
$D049$	Dummy, 1 in 2004 to 2009, 0 otherwise

3.4.4 Import Function (Equation (3.7))

$$IMP_t = 2465085 - -0.04 * QR_{ivt}$$
(4.87) (-2.00)

$$- 442073 * [(WP_t / (GDPD_t / 100)) / (RPR_t (GDPD_t / 100))] - 1181433 * D7794$$
(-1.96) (–5.71)

$$- 1064766 * D97 - 802691 * D001$$
(–3.09) (–3.21)

$AdjR^2 = 0.60$ $DW = 2.15$

IMP	Import of rice in Bangladesh
QR_{ivt}	Total rice production
$[(WP_t / (GDPD_t / 100)) / (RPR_t (GDPD_t / 100))]$	Ratio of world price and retail price
$D7794$	Dummy, 1 in 1977 to 1994, 0 otherwise
$D97$	Dummy, 1 in 1997, 0 otherwise
$D001$	Dummy, 1 in 2000 to 2001, 0 otherwise

3.4.5 Stock Function (Equation (3.8))

$$STC_t = 261002 - 80704 * TREND + 0.82 * (QR_{ivt} - QR_{iv(t-1)})$$
(1.44) (–4.83) (12.18)

$$- 71.81 * [(RPR_t (GDPD_t / 11)) - (RPR_{t-1} / (GDPD_{t-1} / 100))] - 928485 * D956$$
(–2.30) (–3.36)

$$+ 1901663 * D08 - 5052962 * D09$$
(4.34) (3.99)

$AdjR^2 = 0.93$ $DW = 2.03$

STC_t	Quantity of stock of rice in Bangladesh
$TREND$	Time trend from 1977 to 2009
$QR_{ivt} - QR_{iv(t-1)}$	Changes in quantity of stock of rice
$[(RPR_t (GDPD_t / 11)) - (RPR_{t-1} / (GDPD_{t-1} / 100))]$	Retail price of rice in Bangladesh
$D956$	Dummy, 1 in 1995 to 1996, 0 otherwise
$D08$	Dummy, 1 in 2008, 0 otherwise
$D09$	Dummy, 1 in 2009, 0 otherwise

3.4.7 Per Capita Demand Function ((Equation (3.10))

$$DDR_t = 229 - 0.005 * RPR_t / (GDPD_t / 100) + 0.004 * RPW_t / (GDPD_t / 100)$$
(9.68) (–4.32) (2.82)

$$-002 * (GDP_t / POP_t) / (GDPD_t / 100) + 38.95 * D779 + 14.40 * D826$$
(–1.52) (3.53) (2.61)

$$-32081 * D729 - 12.96 * D045 + 49.46 * D08$$
(–5.90) (–2.35) (4.47)

$AdjR^2 = 0.75$ $DW = 2.18$

DDR_t	Per capita demand for rice
$RPW_t / (GDPD_t / 100)$	Realized retail price of rice
$RPW_t / (GDPD_t / 100)$	Realized retail price of wheat
$(GDP_t / POP_t) / (GDPD_t / 100)$	Realized per capita income
$D779$	Dummy, 1 in 1977 to 1979, 0 otherwise
$D826$	Dummy, 1 in 1982 to 1986, 0 otherwise
$D729$	Dummy, 1 in 1992 to 1997, 0 otherwise
$D045$	Dummy, 1 in 2004 to 2005, 0 otherwise
$D08$	Dummy, 1 after 2005, 0 otherwise

3.4.9 Price Linkage Function (Equation (3.12))

$$SFP_t = 639 + 0.41 * RPR_t + 831.41 * D882 + 1478.68 * D07 + 1687.96 * SHIFT08$$
(1.53) (11.54) (2.35) (1.82) (2.31)

$AdjR^2 = 0.92$ $DW = 2.08$

SFP_t	Farm price of rice in Bangladesh
RPR_t	Retail price of rice in Bangladesh
$D882$	Dummy, 1 in 1988 to 1992, 0 otherwise
$D07$	Dummy, 1 in 2007, 0 otherwise
$SHIFT08$	Dummy variable, 1 after 2008, 0 otherwise

3.5.1 Procurement function (Equation (3.13))

$$GQR_t = -1760401 + 0.08 * QR_{ivt} + 136 * [(P_{GQRt} / (GDPD_t / 100)) - (SFP / (GDPD_{t-1} / 100))]$$
(4.09) (12.46) (5.37)

$$-0.53 * PBES_{t-1} + 95142 * D944 + 559987 * D06 - 73261 * D07 - 340110 * D09$$
(–4.42) (87.75) (2.35) (–2.55) (2.40)

Sigma value = 87436

GQR_t	Public distribution
$[(P_{GQRt} / (GDPD_t / 100)) - (SFP / (GDPD_{t-1} / 100))]$	Difference between procurement price and farm price Change in realized retail price of rice
$PBES_{t-1}$	Public beginning stock
$D944$	Dummy, 1 in 1994 to 2004, 0 otherwise
$D06$	Dummy, 1 in 2006, 0 otherwise

$D07$	Dummy, 1 in 2007, 0 otherwise
$D09$	Dummy, 1 in 2009, 0 otherwise

3.5.2.1 Public import function (Equation (3.14))

$$PBIMP_t = 712288 + 119310^* T94 - 0.14^*(QR_{ivt} - QR_{iv(t-1)})$$
$$(3.09) \quad (4.78) \quad (-3.55)$$
$$- 1152347^*[(WP_t / (GDPD_t / 100)) / (RPR_t (GDPD_t / 100))]$$
$$(-3.46)$$
$$+ 614587^* D956 - 814482^* D004 - 621585^* D067$$
$$(3.92) \quad (-4.47) \quad (-4.08)$$

$AdjR^2 = 0.82$ $DW = 2.70$

$PBIMP_t$	Public import of foodgrain
$T94$	Time trend from 1994 to 2009
$QR_{ivt} - QR_{iv(t-1)}$	Change in rice production
$[(WP_t / (GDPD_t / 100)) / (RPR_t (GDPD_t / 100))]$	Ratio of world price and retail price
$D956$	Dummy, 1 in 1995 to 1996, 0 otherwise
$D004$	Dummy, 1 in 2000 to 2004, 0 otherwise
$D067$	Dummy, 1 in 2006 to 2007, 0 otherwise

3.5.2.2 Private import function (Equation (3.15))

$$PVIMP_t = 2643443 - 0.42^*(QR_{ivt} - QR_{iv(t-1)})$$
$$(8.19) \quad (-7.91)$$
$$- 1680719^*[(WP_t / (GDPD_t / 100)) / (RPR_t (GDPD_t / 100))]$$
$$(-4.96)$$
$$-1855397^* D94 + 826989^* D96 - 951632^* D97 + 2579231^* D99 + 1451761^* D08$$
$$(-9.07) \quad (4.36) \quad (-5.54) \quad (11.95) \quad (5.00)$$

$AdjR^2 = 0.94$ $DW = 2.07$

$PVIMP_t$	Private import of foodgrain
$QR_{ivt} - QR_{iv(t-1)}$	Change in rice production
$[(WP_t / (GDPD_t / 100)) / (RPR_t (GDPD_t / 100))]$	Ratio of world price and retail price
$D94$	Dummy, 1 in 1994, 0 otherwise
$D96$	Dummy, 1 in 1996, 0 otherwise
$D97$	Dummy, 1 in 1997, 0 otherwise
$D99$	Dummy, 1 in 19999, 0 otherwise
$D08$	Dummy, 1 in 2008, 0 otherwise

3.5.3 Public distribution function (Equation (3.16))

$$PDS_t = 1607052 + 0.23.33*[(RPR_t / (GDPD_t / 100)) - (RPR_{t-1} / (GDPD_{t-1} / 100))]$$
(4.09) (2.35)

$$-129.96 * P_{PDSt} / (GDPD_t / 100) + 0.27* PBES_{t-1} + 361739* D946 + 372712* D990$$
(–34.01) (2.49) (14.38) (73.76)

$$-14115* D034 - 340806* D07 + 717117* D08$$
(–14.55) (–41.60) (88.84)

Sigma value = 80679

PDS_t	Public distribution
$[(RPR_t / (GDPD_t / 100)) - (RPR_{t-1} / (GDPD_{t-1} / 100))]$	Change in realized retail price of rice
$P_{PDSt} / (GDPD_t / 100)$	Realized subsidized price of rice
$PBES_{t-1}$	Public beginning stock
$D946$	Dummy, 1 in 1994 to 1996, 0 otherwise
$D990$	Dummy, 1 in 1999 to 2000, 0 otherwise
$D034$	Dummy, 1 in 2003 to 2004, 0 otherwise
$D07$	Dummy, 1 in 2007, 0 otherwise
$D08$	Dummy, 1 in 2008, 0 otherwise

3.5.5 Private stock Function (Equation (3.18))

$$PVSTC_t = -1554394 + 101041* T94 + 0.59*(QR_{ivt} - QR_{iv(t-1)})$$
(–3.92) (2.16) (2.92)

$$-321*[(RPR_t (GDPD_t / 11)) - (RPR_{t-1} / (GDPD_{t-1} / 100))] + 914404 * D970$$
(–1.84) (2.01)

$$+ 2923440* D08 - 1598114* D09$$
(2.48) (–2.17)

$AdjR^2 = 0.93$ $DW = 2.03$

$PVSTC$	Change in price stock of rice
$T94$	Time trend from 1994 to 2009
$QR_{ivt} - QR_{iv(t-1)}$	Changes in quantity of stock of rice
$[(RPR_t (GDPD_t / 11)) - (RPR_{t-1} / (GDPD_{t-1} / 100))]$	Change in retail price of rice
$D970$	Dummy, 1 in 1997 to 2000, 0 otherwise
$D08$	Dummy, 1 in 2008, 0 otherwise
$D09$	Dummy, 1 in 2009, 0 otherwise

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