Climate change, crop productivity and regional growth disparity in Bangladesh: an analysis using district level Computable General Equilibrium (CGE) model

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Abstract

Agriculture is vulnerable to climate change. Although the impacts of climate change on agriculture have widely been examined in Bangladesh, a detailed district level impact analysis has not been undertaken so far. Such an analysis is very important considering growth disparities among sixty four administrative districts in the country. The main contribution of this paper, therefore, is to project the growth disparities and income loss for the poor population under 'worst', 'medium' and 'optimistic' climate induced crop productivity loss scenarios for Bangladesh by developing a sixty four district level multiregional computable general equilibrium model for the first time.

Keywords: Climate change; Regional disparities; Computable General Equilibrium model; Bangladesh; Q540, R110, D580

1. Introduction:

Climate change is one of the greatest challenges facing the world today. On the basis of available strong evidence there is a clear consensus among researchers of climate change on two key issues. Firstly, global climate change is real and it is happening. Secondly it is occurring at an alarming rate (IPCC, 2014). It has attracted global attention because of its threat to humanity and the multidimensional nature of the threat at global, regional and local levels. The earth's average temperature has increased approximately 0.8 °C since the early 20th century and it has been accompanied by a steady increase in the number and severity of climate-related natural disasters, such as cyclonic storms, floods, droughts, and heatwaves (Bandara & Cai, 2014).

As a heavily weather dependent sector, agricultural has been one of the most vulnerable sectors to climate change in many developed and developing countries (FAO, 2015). However, climate change is likely to have disproportionate physical as well as economic impacts on developing countries rather than developed countries (Burke, Hsiang, & Miguel, 2015). It might also be responsible to exacerbate poverty-stricken countries even poorer by 2100.

Bangladesh is one of the most vulnerable countries to climate change among developing countries. Among the South Asian countries, Bangladesh forms a fascinating case study due to several reasons. Firstly, Bangladesh is one of the most densely populated countries in the world, where 31.5% out of total 159 million populations live below country's' national poverty line (World Bank, 2014). Secondly, it is an agrarian country where agricultural sector plays an important role in country's economy contributing 20% to the national GDP and 48% to country's total employment (ADB, 2014). Thirdly, However, in recent years, the agricultural sector in Bangladesh has been greatly affected by temperature rise, precipitation changes, and salinity intrusions (Ali, 2006; Ruane et al., 2013).Therefore, the growth rate of real GDP of the agriculture sector declined from 3.20 % in 2008-09 to 2.17 % in 2012-13 (BBS, 2013)[1]. Finally, it has been projected that country's annual mean temperature is likely to increase from 1.6°C to 3.1°C corresponding with the mean sea level rise of 0.88cm by the end of this century (MOEF, 2005; Rajib, Rahman, & McBean, 2011; Yu et al., 2010). It is widely accepted that climatic change have the potential to affect the country's agriculture sector directly in the near future and it's national and district level economy.

While there is a growing body of empirical literature examining the impacts of climate change in Bangladesh along with other south Asian countries by using sophisticated analytical techniques (See e.g, ADB, 2014; Bandara & Cai, 2014; Cai, Bandara, & Newth, 2016; Hertel, Burke, & Lobell, 2010), there is a large body of literature on the link between temperature increase and impacts on agriculture only focusing on Bangladesh. In terms of the modelling techniques used in evaluating the impact of climate change on agriculture, there are two main categories of climate related studies in the literature focusing only on Bangladesh. The first category of studies has projected the impacts of climate change on agriculture by using biophysical modelling (Chen, McCarl, & Chang, 2012; Iqbal & Siddique, 2014; Knox, Hess, Daccache, & Wheeler, 2012; Ruane et al., 2013). The second category of literature has measured the related economic costs by using partial equilibrium modelling framework[2] (IFPRI, 2013; Kobayashi & Furuya, 2011; Sarker, Alam, & Gow, 2012; Yu et al., 2010). However, many researchers have pointed out the drawbacks of using partial equilibrium modelling framework for climate impact assessments mainly because climate change is global and economy-wide phenomenon and its impacts cannot be captured in isolation within a partial equilibrium framework. Notably, a few studies are based

[1] BBS= Bangladesh Bureau of Statistics

[2] Partial equilibrium model estimates the economic impact of any external shocks for few markets, while it does not consider the economy wide impacts (Bandara, 1991).

on the general equilibrium framework[3] to simulate the macroeconomic impacts of climate change and sea level rise for Bangladesh either nationally or regionally using the 17 agro ecological zones (ADB, 2014; Banerjee, Mahzab, Raihan, & Islam, 2015; Paul & Thurlow, 2008; Thurlow, Paul, & Yu, 2012; Yu et al., 2010). However, none of those studies have developed a multiregional district level Computable General Equilibrium (CGE) model for Bangladesh. Therefore, the main contribution and innovation of this study is to develop the first ever (CGE) model for Bangladesh to bridge the knowledge gap in understanding the district level growth disparities and average income loss of the poor population due to climate change in Bangladesh by 2030. The specific objective of this study is to identify and quantify the macro economic impacts of climate change induced crop yields loss for 64 districts in Bangladesh using the regional CGE model. Further, it aims to examine whether the existing district level growth disparities in Bangladesh will significantly change in the near future as a consequence of global warming. Moreover, simulations are carried out to analyse how the average income of poor population in both poverty stricken and least poverty stricken districts are going to be affected by 2030.

The reminder of this paper is structured as follows. Section 2 provides an overview of the relationship between climate change, crop productivity loss, regional growth disparities and poverty in other countries in general and Bangladesh in particular. Section 3 presents a brief description of the district level top down CGE model of the Bangladesh economy. Section 4 discusses simulation results both at national and district levels and the final section provide the concluding remarks and policy recommendations.

3. Climate change and its impacts on agriculture, regional disparities and poverty

Although there is substantial evidence to support that climate change is real and it is occurring rapidly as noted in the introduction, there is still a debate on the magnitude of climate change and the impact of climate change. According to Christensen et al. (2007), the annual minimum, median and maximum temperature increase for the South Asian countries are likely to be 2.0°C, 3.3°C and 4.7°C under A1 scenario by 2100 respectively. Further, the mean temperature projection is likely to be approximately 1.5°C to 2.0°C for Asia by 2030. The impacts of climate change are expected to hit hardest on the agriculture sector as it is one of the climate dependent

[3] General equilibrium model estimates the impact of any external shock not only on the directly affected sectors of the economy but also the all the sectors of the economy through spill over effects.

human activities (Hertel et al., 2010). Despite the amount existing literature discussing that area; the uncertainty about the extent of positive carbon fertilization effects over the negative effects on crop production is becoming prominent. For example, Cline has predicted that the loss in agriculture due to climate change worldwide will be moderate by the end of this century without any carbon fertilization effects (Cline, 2007). A recent study by Nelson et al. (2014), concluded that the mean potential global crop yield reduction would be 17% by 2050 compared to the base year condition without any positive carbon fertilization effect. Moreover, global warming is potentially responsible for an increase in the variability of agricultural crop yields, crop land productivity, yields price, consumption and trade pattern worldwide by 2050 respectively. Furthermore, Challinor et al. (2014) specified that rice and wheat crop production is likely to decline for both tropical and temperate countries due to the potential increase of local warming by 2°C despite any adaptation measures taken by those regions. However, global warming has disproportionate impacts between developed and developing countries (Cline, 2008). Though developed countries are more responsible for global warming, its impacts are going to hit the developing countries hardest by directly lowering the countries agriculture production and indirectly its economic growth (Das Gupta, 2014). Despite the carbon fertilization effects, Cline (2008) has estimated that the crop production loss for Latin America, African and South Asian countries is likely to be dramatic and the mean crop yield loss across Asia and Africa is likely to be 8% by 2050 (Knox et al., 2012).Though climate change is a global phenomenon; its impacts vary from one country to other. Moreover, those potential impacts might also differ even across regions within a country.

Climate change induced crop yield losses might affect the existing inter or intra-regional disparities and poverty (Iglesias et al., 2012). Regional economic disparities are one of the prominent features in both developed and developing nations (Cherodian & Thirlwall, 2015). Disparities are always perceived as a threat to economic growth and development in any economy (Patra, 2014). However, disparities are more prominent within developing rather than developed countries (Shankar & Shah, 2003). Most of the developing countries are facing inter or intra-regional growth and income inequality even if the national level economic growth in those countries is increasing. For example, a number of recent studies have focused on important issues related regional disparities in south Asian countries like India, Pakistan and Sri Lanka (Butt & Bandara, 2009; Cherodian & Thirlwall, 2015; Naranpanawa & Arora, 2014; Patra, 2014; Wijerathna, Bandara, Smith, & Naranpanawa, 2014).

While considering the relation between climate change and poverty, Mendelsohn et al. (2007), proved that climate induced crop productivity loss definitely affects the existing poverty level within a country like the US. Further, results suggest that global warming is likely to increase the poverty through the loss of agricultural productivity. A recent study by Burke et al. (2015), provided evidence on the economic consequences of climate change for both developed and developing countries and found that in relative terms, the average decline in income for 40% of the poorest countries is likely to be 75% by 2100. However, the richest 20% of countries is likely to experience slight gains.

2.1 Climate change, agriculture, regional disparity and poverty in Bangladesh:

The total population of Bangladesh is around 144 million according to the 2011 population census report, while the population density per square kilometre is around 964 (BBS, 2013). Though the growth rate of real GDP has increased from 5.87 % in 2007-08 to 6.06 % in 2012-13; approximately 35 % of the country's total population live below the national poverty line. According to the World Bank updated poverty reports, absolute number of poor population in each district can be measured by using two poverty lines (World Bank, 2009). An upper poverty line specifies a higher level of per capita household expenditure than the lower poverty line; therefore a greater number of populations are identified as poor under upper poverty line in comparison to the lower poverty line. On average, the number of poor population under upper poverty line is 20% higher than the lower poverty line. The head count poverty rate of Bangladesh is 31.5% and 17.6% according to upper and lower poverty line. According to the lower poverty line, the maximum and minimum percentages of poor population are 44.3% and 0.8% respectively. Similarly, according to the upper poverty line the maximum and minimum percentages of poor population are 63.7% and 3.6% respectively. In the current study, we have selected the top ten districts with less percentage of poor population (least poverty stricken districts) and bottom ten districts with a larger percentage of poor population (poverty-stricken districts) out of total 64 districts to analyse the impact of climate change on reginal disparity and poverty in Bangladesh. The poverty-stricken districts are namely, Kurigram (44.3%[4]), Barisal (39.9%), Shariatpur (34.4%), Jamalpur (34.2%), Mymensingh (32.3%), Pirojpur (30.9%), Gaibandha (30.3%), Chandpur (30.3%), Rangpur (30.1%), Satkhira (29.7%) and least poverty stricken districts are namely, Kushtia (0.8%), Noakhali (3.4%), Chittagong (4%), Dhaka (4.9%), Meherpur (5.1%), Bogra (6.7%), Rangamati (6.8%), Naogaon (7%), Narail (7.7%), Manikganj

[4] All the parentheses numbers represent the percentage of poor population in different districts.

(8%) respectively. Figure 1 represents those above mentioned twenty selected districts within Bangladesh, based on the proportion of poor population.

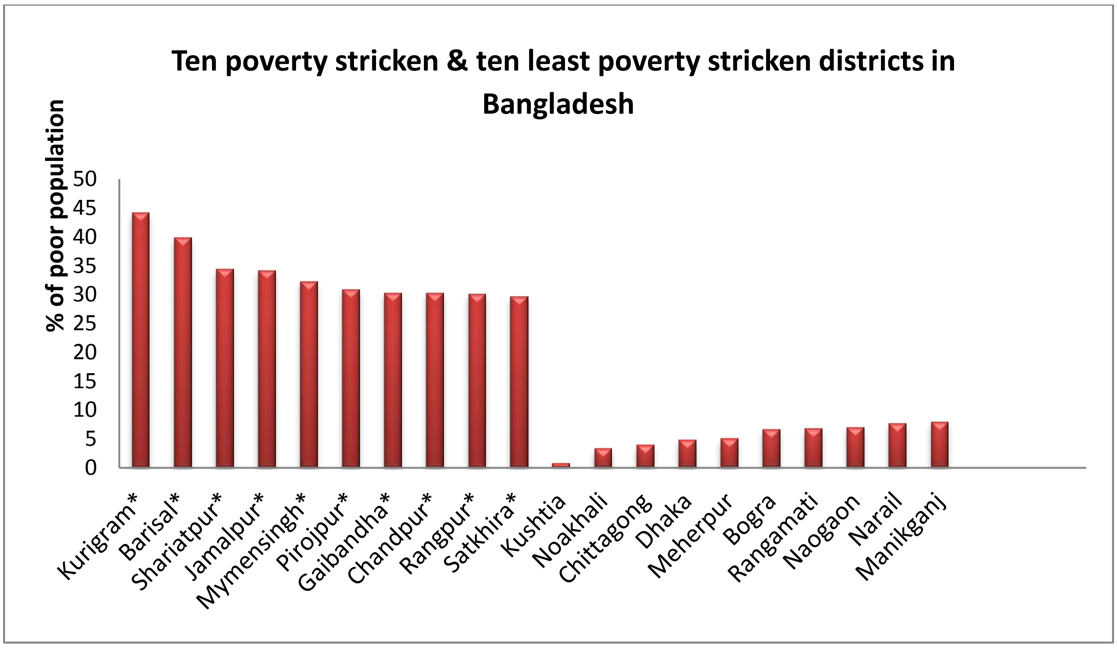

Figure1. Percentage of poor population in ten poverty stricken districts with star sign and ten least poverty stricken districts within Bangladesh (Source: Graphed by the authors based on the combined report by World Bank, Bangladesh Bureau of Statistics (BBS), and UNWFP[5] 2010)

In considering the regional growth disparities, there is a paucity of literature in analysing the inter district growth disparities and the reasons behind those disparities in Bangladesh (Amin, 2008; Khondker & Mahzab, 2015; Rahman, 2007; Rahman & Kazal, 2015; Rahman & Salim, 2013). According to Amin (2008), the important behind the significant growth disparity is the income inequality among the 64 districts in Bangladesh. Though food security problem in Bangladesh have been reduced during the last three decades, people in the northern "Monga[6]" prone regions (which we have mentioned in introduction) are particularly facing seasonal food insecurity problem compare to the other regions of Bangladesh (Ahamad et al., 2013). In line with this, the other key aspect stimulating the growth disparity is the different rate of total factor productivity growth in agriculture across regions in Bangladesh (Rahman, 2007). Though it has been predicted that the agricultural growth diversity is likely to disappear in the long run, some authors have provided evidence for the significant existence of the growth disparity among

[5] UNWFP= United Nations World Food Programme (UNWFP, 2010)

[6] The word "Monga" is used to describe the situation of poverty and hunger as a result of low income, high food price, food shortages (Ahamad, Khondker, Ahmed, & Tanin, 2013).

Bangladesh regions. According to Khondker and Mahzab (2015), the extent of divergence and the income inequality have increased from 2005 to 2010 compared to the previous two consecutive five year time periods. Moreover, there is a likelihood that those disparities among districts might also increase over time. While considering agricultural productivity, the overall agricultural productivity growth due to technological progress is higher in Chittagong, Rajshahi and Rangpur districts and lower in Dhaka and Khulna districts respectively (Rahman & Salim, 2013). Moreover, the production pattern in most of the agricultural crop land area has diversified significantly from one district to another within Bangladesh (Rahman & Kazal, 2015). The land allocation has changed from producing traditional rice, minor cereals, oilseeds, pulses to high yielding rice, spices and vegetables over the time period of 1990 to 2008 for many regions except Khulna, Faridpur and Sylhet regions respectively.

The Bangladeshi economy is likely to be more vulnerable to climate change in comparison with other South Asian countries (Cai et al., 2016). The increasing annual average temperature, the uncertainty of the rates of precipitation, floods and extreme weather events in Bangladesh are becoming main features of climate change. All of these have negative impacts on the winter crops such as wheat, boro rice, vegetables production (Hossain & Silva, 2013). However, the resulting impacts are likely to vary across different regions not only due to changes in temperature and precipitation projections over the time periods but also due to the use of different analytical techniques in evaluating the impact of climate change on crop productivity within Bangladesh. A handful of existing literature has projected the impacts of climate change on crop productivity in Bangladesh agriculture (ADB, 2014; Chen et al., 2012; Cline, 2007; Hertel et al., 2010; IFPRI, 2013; Knox et al., 2012; Ruane et al., 2013; Yu et al., 2010) (see Table 1).

Table 1: A brief summary of literature on climate change impacts on crop production across regions in Bangladesh

Source	Climate change (Temperature & Precipitation)	Bangladesh Regions	Crops (Rice[7], Wheat, Maize)	Crop loss (%)		
(ADB, 2014)	A1B scenario: 1.9^0 C by 2030 2.5^0 C by 2050 4.2^0 C by 2080	Khulna division(1), Barisal divion (2), Chittagong division (3)	Rice Aus (a) Aman(b) Boro(c)	**2030:** 1(a,b,c)= -2.8,-2.6,-2.2 2(a,b,c)= -3.3,-3.0,-2.6 3(a,b,c)=-5.3,-4.9,-4.6 **2050:** 1(a,b,c)=-6.2,-5.6,-4.9 2(a,b,c)=-7.1,-6.8,-6.4 3(a,b,c)=-16.5,-15.2,-13.9 **2080:** 1(a,b,c)=-14.0,-13.2,-12.3 2(a,b,c)=-16.5,-15.2,-13.9 3(a,b,c)=-21.2,-19.9,-18.6		
(Chen et al., 2012)	1^0 C: Median projections of temperature changes from 1980-2000 to 2020-2040	Bangladesh	Rice	-2		
(Cline, 2007)	Avergae monthly teperature will increase upto 5^{0}C by 2070-2099 from 1961-1990	Global including Bangladesh	All Crops	-10 to -25		
(Yu et al., 2010)	Median temp (base line priod 1970-1999): 1.1^0 C by 2030 1.6^0 C by 2050 2.6^0 C by 2080	16 regions including coastal within Bangladesh	Rice Aus Aman Boro Wheat	**2030** -0.27 -0.37 -3.06 +2.05	**2050** -1.52 -0.62 -4.74 +3.44	
(IFPRI, 2013)	Changes for 2050 from 2000: 0.3 C to 2.6 C daily (without adaptation)	Bangladesh	Rice Wheat Maize Sugarcane	-6.6 to -7.5 -18.7 to -20.4 -1.4 to -2.8 -10.6		
(Knox, Hess, Daccache, & Ortola, 2011)	Time slice wise: 2020 2050 2080	Bangladesh	Rice	**2020** -5	**2050** -6.5	**2080** -10

[7] According to the cropping seasons, quality and characteristics there are three types of rice in Bangladesh: Aus, Aman and Boro.

(Hertel et al., 2010)	2030 (without adaptation)	Global including Bangladesh		'low'	'Medium'	'High'
			Rice	-10	-3	4
			Wheat	-10	-3	4
			Oilseeds	-10	-3	4
			Grains	-17	-10	-3
			Sugar	0	0	0
			Cotton	-10	-3	4
			Other crops	-10	-3	4

Considering different modelling results Cline (2007) has concluded that the overall range of potential crop loss in Bangladesh is likely to be 10% to 25 % with and without carbon fertilization by the end of this century. A global study by Hertel et al. (2010) estimated the crop productivity loss for six major and minor crops in Bangladesh for 'low', 'medium' and 'high' climate induced crop productivity loss scenario in Bangladesh without any adaptation measures. In brief, there will be a change in the percentage of productivity from a positive gain to huge negative losses for rice, wheat, oilseeds and grains by 2030 respectively. Kobayashi and Furuya (2011), showed that the impacts of temperature rise on rice production is likely to vary substantially even from one region to another within Bangladesh by 2050. The mostly affected divisions will be Chittagong and Rajshahi and the moderately affected divisions will be Khulna and Barisal by the end of 2050. Moreover, a review by Knox et al. (2011) showed the impacts of climate change on major crops like rice, wheat, maize for developing countries from Africa and Asia. The rice yields loss is likely to be 5% by 2020, 6.5% by the 2050s and 10% by the 2080s for Bangladesh. Two recent studies by the International Food Policy Research Institute (IFPRI, 2013) and the Asian Development Bank (ADB, 2014) have estimated an average rice productivity loss of from 6 to 10% by the end of 2030 using the DSSAT crop model. Understanding the relation among climatic events, agricultural loss, and poverty and growth disparity is very complex. A report by UNDP (2009), depicts how different climatic events such as floods, global warming, precipitation changes have a different extent of relationship among crop loss, poverty and economic growth in Bangladesh. It has found that the larger percentage of crop production loss would increase the poverty impacts by the same amount by the end of this century. In line with that, the negative impact on economic growth might vary from 1% to 17% by 2100. Therefore, it is necessary to explore how the impacts of near future climate induced crop productivity loss will affect the district level growth disparity and average income loss of the poor population within Bangladesh.

3. Multiregional CGE model for Bangladesh:

In this study, we develop a comparative static multiregional "top-down" CGE model for Bangladesh which consists of 64 districts[8]. To our knowledge, this is the first attempt of developing a district wise CGE model for Bangladesh. The theoretical structure of this model and empirical implementation of closely follows the well-known ORANI model of the Australian economy and its "top-Down" regional extension (Dixon, Parmenter, Sutton, & Vincent, 1982). The database for the base year (2007) of the core model of the Bangladeshi economy is obtained from the Global Trade and Analysis Project (GTAP) version seven (Narayanan, Walmsley, & Editors, 2008). To develop the "top-down" regional extension district level data from sources such as Bangladesh Bureau of Statistics (BBS, 2013), World Bank, Statistical Yearbook of Bangladesh, Ministry of Environment and Forestry, World Food Programme and Bangladesh household income and expenditure survey data (HIES, 2010) are used. The national level economic impact projections are disaggregated into district levels. This model encompasses 17 commodities produced by 17 industries[9].

ORANI was the first Australian CGE model developed in the late 1970s as part of IMPACT projects by the Australian Government (Dixon et al., 1982).

The theoretical foundations of this model are based on the following neoclassical theory assumptions. Firstly, producers, consumers, and other agents in the market are price takers. Secondly, producers are profit maximisers and consumers' are utility maximisers. Also, the production function is of nested types where there is a combination of both 'Leontief' and 'Constant elasticity of substitution (CES)' production functions. Thirdly, there are three types of inputs of production; primary factors of production; skilled and unskilled labours; and imported and domestic inputs. Fourthly, all markets are assumed to be cleared or in equilibrium in all the times. Last but not the least, Government expenditures and household numbers are exogenously determined in the model.

We do not present the equation system of the core national model of the Bangladesh economy since the equation system of the Bangladesh national model closely follows the ORANI model (Dixon et al., 1982). However, we will present the equation system of the "top-down" regional extension in this paper since that will help us to present our results.

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[8] Bangladesh has total eight divisions with 64 districts. This paper is interchangeably using districts or regions.

[9] To simplify, we have aggregated the manufacturing, mining and service sectors in our model.

The regional disaggregation of that model is based on the ORANI Regional Equation System (ORES)10 (Dixon et al., 1982). ORES is based on a technique developed by Leontief, Morgan, Polenske, Simpson and Tower (LMPST, 1965) so as to disaggregate the results of the national input output model into regions (Naranpanawa & Arora, 2014). This method is more popular to disaggregate the national level simulation results into different regions. This method has widely been used by other authors worldwide in a 'top-down' manner (for other applications see (Butt & Bandara, 2009); (Dixon, Rimmer, & Tsigas, 2007); (Naranpanawa & Arora, 2014). According to Dixon et al. (2007, p. 53),

"Tops-down model are most suitable for analysis of national policy changes (such as the removal of tariffs and quotas) that could be expected to have little effect on the relative costs of sourcing commodities from different regions".

The above mentioned LMPST approach is based on the following technical assumptions. Firstly, there is no technological difference for industry in each region. Secondly, each region contains two types of commodities, 'Local' and 'National'. Local commodities are produced and sold within the local region. In any region, the output of local commodities adjusts to satisfy the intermediate and investment demand by other industries along with household demand within that region. National commodities are those for which the regional output expands in accordance with the national output. Finally, the regional pattern of production is independent with regional pattern of demand for national commodities.

Following are the description of the LMPST model which has modified for using with national level ORANI model[11]

Required set names and its components[12]for our model,

U= all commodities ($1 \ldots 17$)

K= all industries ($1 \ldots 17$)

N= industries producing national commodities (national industries) ($1,2$)

M=industries producing local commodities (local industries) ($1, \ldots 15$)

[10] ORES is based on a techniques, developed by Leontief et al. (1965) in order to disaggregate the results of a national input-output model into regions.

[11] Technical model descriptions are heavily drawn from (Dixon et al., 1982 Chapter-6).

[12] N.T: industry and commodity classifications in ORANI are such that no industry can produce both local and national commodity together, which implies N∩M is empty.

H= national commodities ($1,2$)

L= local commodities ($1,2$)

R= number of regions ($1 \dots 64$)

First, the activity levels for the national industries can be defined by

$$Z_n^r = Z_n G_n^r \quad \text{for all n } \epsilon \text{ N and } r = 1 \dots 64 \tag{1}$$

Where, Z_n^r is the output of industry n in region r and G_n^r is the base- period proportion of the aggregate output of industry n which is produced in region r. Since G_n^r is constant, therefore equation becomes (if we transform equation 1 as percentage change form)

$$z_n^r = z_n \text{ (Since, } dG_n^r = 0\text{) for all n } \epsilon \text{ N and } r = 1 \dots 64 \tag{2}$$

If there is an increase in the aggregate output of any national industry by one percent, then the output of that industry will increase in same proportion for each region. Also, it can be assumed that the commodity composition of output in national industries is constant across all regions.

For local commodities,

Aggregate output of any local commodity in a region must be equivalent to the aggregate demand for the commodity in that region, that is:

$$\begin{aligned} X_{(i1)}^{(0)r} = & \sum_{n \in N} \left(A_{(i1)n}^{(1)} + Z_n^r \right) + \sum_{m \in M} \left(A_{(i1)m}^{(1)} + Z_m^r \right) \\ & + \sum_{n \in N} \left(A_{(i1)n}^{(2)} + Y_n^r \right) + \sum_{m \in M} A_{(i1)m}^{(2)} Y_m^r + X_{(i1)}^{(3)r} + X_{(i1)}^{(5)r} \\ & + \sum_{u \in U} \sum_{s=1}^{2} \sum_{n \in N} \sum_{h=1}^{2} A_{(i1)}^{(us)nh} X_{(us)n}^{(h)r} + \sum_{u \in U} \sum_{s=1}^{2} \sum_{m \in M} \sum_{h=1}^{2} A_{(i1)}^{(us)mh} X_{(us)m}^{(h)r}) \\ & + \sum_{u \in U} \sum_{s=1}^{2} \sum_{h=3,5} A_{(i1)}^{(us)h} X_{(us)}^{(h)r} + \sum_{u \in U} A_{(i1)}^{(u1)4} X_{(u1)}^{(4)r}, \end{aligned}$$

$$i \in L, r = 1, \dots, 64 \tag{3}$$

Where,

$A_{(ik)k}^{(h)}$ = direct input of domestically produced commodity i required per unit output $(h = 1)$ or capital information $(h = 2)$in industry k;

$A_{(i1)}^{(us)kh}$= the input of domestically commodity i required as a margins service per unit direct flow of commodity u from source s to industry k for purpose h.

And $A_{(i1)}^{(us)h}$ = the input of domestic commodity i required as a margins service per unit direct flow of commodity u from source s to final demand category$h$.

However, A represents the technology. However, in this model the technology in each industry is independent of its regional location.

The percentage change form of equation is,

$$
\begin{aligned}
x_{(i1)}^{(0)r} = \sum_{n\in N} \left(a_{(i1)n}^{(1)} + z_n^r\right) B_{(i1)n}^{(1)r} + \sum_{m\in M} \left(a_{(i1)m}^{(1)} + z_m^r\right) B_{(i1)m}^{(1)r} \\
+ \sum_{n\in N} \left(a_{(i1)n}^{(2)} + y_n^r\right) B_{(i1)n}^{(2)r} + \sum_{m\in M} \left(a_{(i1)m}^{(2)} + y_m^r\right) B_{(i1)m}^{(2)r} + x_{(i1)}^{(3)r} B_{(i1)}^{(3)r} + x_{(i1)}^{(5)r} B_{(i1)}^{(5)r} \\
+ \sum_{u\in U} \sum_{s=1}^{2} \sum_{n\in N} \sum_{h=1}^{2} (a_{(i1)}^{(us)nh} + x_{(us)n}^{(h)r}) B_{(i1)}^{(us)nhr} \\
+ \sum_{u\in U} \sum_{s=1}^{2} \sum_{m\in M} \sum_{h=1}^{2} (a_{(i1)}^{(us)mh} + x_{(us)m}^{(h)r}) B_{(i1)}^{(us)mhr} \\
+ \sum_{u\in U} \sum_{s=1}^{2} \sum_{h=3,5} \left(a_{(i1)}^{(us)h} + x_{(us)}^{(h)r}\right) B_{(i1)}^{(us)hr} + \sum_{u\in U} \left(a_{(i1)}^{(u1)4} + x_{(u1)}^{(4)r}\right) B_{(i1)}^{(u1)4r},
\end{aligned}
$$

$i \in L, r = 1, \dots, 64$ (4)

Where, B represents sales shares.

For further simplification, we can assume that in the base period, the relative quantities of good $(i1)$ used for facilitating the domestic $(s = 1)$ and import $(s = 2)$ components of each commodity flow to each industry in each region for reflecting the relative values of these components

$$B_{(i1)}^{(us)khr} = B_{(i1)}^{(u\cdot)khr} S_{(us)k}^{(h)r}, \; i \epsilon L, \; u \epsilon U, \; s = 1{,}2 \; k \epsilon K, \; h = 1, 2 \; r = 1, 2 \ldots 64 \tag{5}$$

Further, with the assumption of no technical change, we have,

$$\sum_{s=1}^{2} x_{(us)k}^{(1)r} B_{(i1)}^{(us)k1r} = z_k^r B_{(i1)}^{(u\cdot)k1r}, \quad i \in L, u \in U, k \in K, r = 1, \ldots, 64 \tag{6}$$

And

$$\sum_{s=1}^{2} x_{(us)k}^{(2)r} B_{(i1)}^{(us)k2r} = y_k^r B_{(i1)}^{(u\cdot)k2r}, \quad i \in L, u \in U, k \in K, r = 1, \ldots, 64 \tag{7}$$

If we assume that $a's = 0$, equation 4 simplifies to,

$$\begin{aligned} x_{(i1)}^{(0)r} = & \sum_{n \in N} \left(B_{(i1)n}^{(1)r} + \sum_{u \in U} B_{(i1)}^{(u\cdot)n1r} \right) z_n^r + \sum_{m \in M} \left(B_{(i1)m}^{(1)r} + \sum_{u \in U} B_{(i1)}^{(u\cdot)m1r} \right) z_m^r \\ & + \sum_{n \in N} \left(B_{(i1)n}^{(2)r} + \sum_{u \in U} B_{(i1)}^{(u\cdot)n2r} \right) y_n^r \\ & + \sum_{m \in M} \left(B_{(i1)m}^{(2)r} + \sum_{u \in U} B_{(i1)}^{(u\cdot)m2r} \right) y_m^r + B_{(i1)}^{(3)r} x_{(i1)}^{(3)r} + B_{(i1)}^{(5)r} x_{(i1)}^{(5)r} \\ & + \sum_{u \in U} \sum_{s=1}^{2} \sum_{h=3,5} B_{(i1)}^{(us)hr} x_{(us)}^{(h)r} + \sum_{u \in U} B_{(i1)}^{(u1)4r} x_{(u1),}^{(4)r} \qquad i \in L, r = 1, \ldots, 64 \end{aligned} \tag{8}$$

The above equations can be solved by providing the values in the right hand side variables. Moreover, we will also be able to solve equation (8) for percentage changes in regional outputs of local commodities; we need to express each of these equation's variables as functions of (i) to make those variables as exogenous at the regional level.

While solving the equations related to regional investments, this model will assume that the proportion of investment by each industry will be similar to the current output proportion.

3.1 Household consumption at the regional level:

For household consumption, the assumption is that in each region there is a link between regional consumption and regional labour income.

We assume that,

$$X_{(us)}^{(3)r} = f_{(us)}^{r}\left(X_{(us)}^{(3)}, \frac{V^r}{V}\right), \qquad u \in U, s = 1,2, r = 1, \dots ,64 \tag{9}$$

Therefore, the household consumption in each region is a function of

$[x_{(us)}^{(3)} = agrregate\ consumption\ of\ good\ (us)]\ \ and$

$\frac{V^r}{V} = \frac{total\ wage\ bill\ in\ region\ r}{economy\ wide\ agrregate\ wage\ bills}.$

The percentage change equations for equation (9) will be,

$$X_{(us)}^{(3)r} = \alpha_{(us)}^{r} x_{(us)}^{(3)} + \gamma_{(us)}^{r}(\vartheta^r - \vartheta), \qquad u \in U, s = 1,2, r = 1, \dots ,64 \tag{10}$$

Where, $\alpha_{(us)}^{r}$= the elasticity in region r of consumption of good (us) with respect to the aggregate consumption of good(us).

$\gamma_{(us)}^{r}$ = the elasticity in region r to the consumption of good (us) with respect to the share of region r in the economy's aggregate wage bill.

Here the assumption is:

$$\alpha_{(us)}^{r} = 1 \tag{11}$$

And

$$\gamma_{(us)}^{r} = \ \epsilon_{(us)}\, \gamma\ , o \leq \gamma \leq 1,\ u\, \epsilon\, U,\ s = 1,2, r = 1, 2 \dots 64 \tag{12}$$

$[N.T$: γ is a parameter which signifies the relation between

regional income with aggregate regional consumption]

And

$\epsilon_{(us)}$ = economy wide household expenditure elasticity of demand for good u from source s

However, for our long run simulation the suitable assumption is,

$$\gamma_{(us)}^{r} = 1 \tag{13}$$

Therefore, substituting long run assumption into equation (10) then it becomes,

$$X_{(us)}^{(3)r} = x_{(us)}^{(3)} + (\vartheta^r - \vartheta) \qquad u \in U,\ s = 1,2, r = 1, 2 \ldots 64 \tag{14}$$

Thus, the changes in regional consumption levels fully reflect the changes in the regional allocation of labour income.

If we consider the wage bill variable, it can also be expressed in terms of wage rates and industry specific employment levels. The percentage change form of the wage bill equation is:

$$\vartheta^r = \sum_{k \in K} (p_{(g+1,1)k}^{(1)} + x_{(g+1,1)k}^{(1)r}) W_k^r , \qquad r = 1, \ldots ,64 \tag{15}$$

(Note that: the wage rate variable $p_{(g+1,1)k}^{(1)}$is without the regional subscript and w_k^r denotes the share of industry k in the aggregate wage bill of region r.

Further, the economy wide wage bill can be expressed as percentage form equation,

$$\vartheta = \sum_{k \in K} (p_{(g+1,1)k}^{(1)} + x_{(g+1,1)k}^{(1)r}) W_k \tag{16}$$

Where, the weights W_k represent the shares by industries in the aggregate wage bill for the economy.

To determine the regional employment in equation (15), the model assumes that the percentage change in employment per unit of output in industry k in each region r is similar as the percentage change in employment per unit of output in industry k for that country. That is,

$$x_{(g+1,1)k}^{(1)r} - z_k^r = x_{(g+1,1)k}^{(1)} - z_k, \qquad k \in K, r = 1, \ldots , 64 \tag{17}$$

This assumption is particularly appropriate for our long run simulation because it is reasonable to assume that the labour-capital ratio moves uniformly across regions. This assumption is possible if we have already assumed that the wage rates move uniformly across regions and capital is inter-regionally mobile, which we have already specified. Therefore, equation (17) seems to be satisfactory assumption for our long run model.

While solving other equations, this model assumes the changes to be exogenous in its regional allocation for Government current expenditure and fixed regional sourcing for international exports from regions.

Finally, by substituting, equation 16 into equation 10, from equation 17 into equation 15 and then into 10, we can achieve:

$$x_{(us)}^{(3)r} = x_{(us)}^{(3)} + \varepsilon_{(us)}\gamma[\sum_{k\in K}(W_k^r - W_k)\left(p_{(g+1,1)k}^{(1)} + x_{(g+1,1)k}^{(1)r}\right) + \sum_{m\in M} W_m^r(z_m^r - z_m)]$$

$$u \in U, \; s = 1{,}2, \; r = 1, 2 \dots 64 \qquad (18)$$

.

In our "top down" model, we have assumed manufacturing and service as national industries and agriculture and mining as local industries. Manufacturing products and services can be traded between different districts. However, agricultural crops can be considered as a non-traded commodity by assuming that the majority of farmers are small land holders and the total demand for agriculture must satisfy district production requirements. Although the "top-down" model has some limitations, such as, being unable to project the regional level policy results, it does provide many advantages because of its data convenience and other reasonable features while projecting and disaggregating the national level policy shocks across regions.

4. Regional Impacts of climate change: Simulation Results

In this study, we conducted the following three simulation experiments to examine the near future impacts of global warming on the national and district level growth disparities and income loss through climate induced agricultural productivity loss in Bangladesh.

The experiments were conducted within the long run macro-economic environment (or closure). In the long run closure, all sectoral capital is endogenous; however, the rate of return is exogenous. Producers have sufficient time to alter the capital stock level consistent with any productivity shocks. In the labour market, we also assume the long run labour market assumption of aggregate employment as exogenous, implies that the economy is in full employment. Moreover, the nominal exchange rate is also exogenous and considered as numeraire. However, the real wage is endogenous, allowing the model to determine it endogenously. Also, number of households and their preferences remain exogenous. Furthermore, there is a link between regional consumption and regional labour income. This CGE model was solved by using the software GEMPACK (Harrison & Pearson, 1998).

In this simulation, we have reduced the total factor productivity loss of different crops for 2030. We did not calculate total factor productivity loss in this study, but have taken loss from another study where three scenarios considered, 'low', 'medium' and 'high' between 2000 to 2030 (Hertel et al., 2010). According to them, the 'low' scenario represents the large crop productivity loss due to extreme climate impacts with frequent temperature change, high crop sensitivity to temperature change and low positive carbon fertilization. Sequentially, 'medium' scenario represents the medium crop productivity loss and the 'high' scenario represents the climate change scenario with slow warming, low crop sensitivity to temperature change and high carbon fertilization. In this paper we have used the climate projections data from (Christensen et al., 2007) where the temperature and precipitation projections have been done for the A1B scenarios over different time periods for different regions worldwide, as used by (Hertel et al., 2010). For the purpose of this paper, we have also used the projected productivity loss values for six crops such as paddy, wheat, oilseeds, grains, other crops and cotton from that study in Bangladesh. However, instead of denoting 'low', 'most likely' and 'high' scenario as specified by (Hertel et al., 2010) we will be denoting 'worst', 'medium', and 'optimistic' climate impacts respectively. Two main reasons for taking those shocks over other studies are as follows: first, this study has estimated the agricultural productivity loss for most likely to most unlikely impacts of future warming for Bangladesh for the near future. Second, the estimated crop productivity loss by other studies available for Bangladesh lies within that range of loss (see table1).

4.1 Macroeconomic and industry Results:

The macroeconomic results of the three simulations in percentage change form are summarized in Table 2.

Table 2. Long run projections of national macroeconomic variables for three

National Macro	Worst (high crop	Medium (medium	Optimistic (Low

variables	productivity loss, Sim 1)	productivity loss, Sim 2)	productivity loss, Sim 3)
Real GDP	-3.50	-1.04	1.36
Aggregate real investment expenditure	-3.88	-1.11	1.41
Average real wages	-4.89	-1.43	1.83
Real Household consumption	-3.50	-1.06	1.39
Aggregate real government demand	-3.50	-1.06	1.39
Consumer price index	-1.75	-0.54	0.73
Aggregate capital stock, rental weights	-4.66	-1.37	1.78

% change from the base year

On the one hand, the third simulation result yields a positive increase not only in the real GDP but also for other macroeconomic variables such as real investment expenditure, real wages as well as real household consumption, real Government demands and real exports. All these suggest that the lower the climate induced agricultural productivity loss due to the improvement through positive carbon fertilization effect, the more likely positive growth for the economy will be stimulated. As can be seen from table 2, some of the industry expansions lead to aggregate capital stock increase by one percent. Similarly, the increasing labour demand for those industries would stimulate the average real wage to increase by one percent compared to the base year. This could then stimulate the real GDP growth rate by 1.35 percent by 2030. However, the medium to high crop productivity loss can have significant negative loss for real GDP and other macroeconomic variables by 2030. A decrease in productivity for staple crops in Bangladesh due to climate change might lead to an increase in production costs of those industries which can then results in an increase in the producers as well as consumers' price. Moreover, an increase in costs of production will lead to the decrease in total production of those commodities. As shown in table 2, those industry contractions would lead average real wages and aggregate capital stock to decrease by one to four percent compared to the base year. This would in turn contribute negatively to the real GDP growth. Furthermore, real household consumption would change negatively by one to three percent. Meanwhile, aggregate demand is also discouraged by decreasing real investment, real Government demand and exports at the rate of one to three percent, respectively.

On the other hand, the national industry level value added results represent 4.16% and 14.88% loss of paddy and wheat production respectively due to the worst scenario of climate change by 2030. Similarly, the service and manufacturing sector loss are 2.21% and 4.96% respectively. These results are consistent with the other existing recent national level CGE studies for Bangladesh. For example, Thurlow et al. (2012), found that the national rice production loss will be 8.8% over 2005-2050. A recent study by Bandara and Cai (2014) projected the decline of real GDP for Bangladesh by 1.6% from baseline by the 2030. Similarly, ADB (2014) estimated a paddy production loss of -0.68% due to 0.9°C – 1.9°C by 2030. These estimated results are also consistent with our medium simulation results of -1.16% real GDP losses under the likely range of temperature increase of 1.0°C to 1.5°C respectively.

4.2 Regional Results

The combined impacts of temperature, precipitation changes and carbon fertilization is likely to have negative growth impacts for all districts of Bangladesh under the worst climate scenario but moderate impacts due to medium scenario and positive growth impacts due to the optimistic climate change scenario by 2030. When we consider the long run impacts of climate change on gross domestic product at the districts level for worst, medium and optimistic scenarios, then the average loss of gross domestic products is 2.60% due to worst climate impacts and 0.76% loss due to medium climate impacts for 64 districts. However, the positive impact due to optimistic climate conditions is likely to be 0.99% for 64 districts in Bangladesh. The minimum percentage loss of GDP is 1% for Patuakhali district in Barisal division and the maximum loss is approximately 4% for Munshiganj district in Dhaka division due to worst productivity loss scenario respectively. However, it is evident that the regional growth results are not significantly dispersed among 64 districts by 2030. To identify it more effectively, we have also calculated the coefficient of variation[13] of factor cost GDP before and after the simulation for both the 64

[13] Coefficient of variation (C_V) = (Standard Deviation/Mean). Before simulation, we calculated the base year factor cost GDP for selected districts followed by coefficient of variation. Similarly, we have calculated the new factor costs GDP for those same districts after the simulation through reducing the amount of GDP by the resulting percentage change gross district product loss. Finally, the coefficient of variation has calculated for those new sets of GDP for 2030.

districts and the 20 selected districts. The coefficients of variation for 64 and 20 selected districts are 1.29, 1.47 before and 1.29, 1.48 after the simulation for worst climate impacts scenario.

Simulation results indicate that, in general, both poverty stricken and least poverty stricken districts are likely to be affected negatively due to climate change; however, the extent of losses between poverty stricken and least poverty stricken districts are different and fascinating (see **Table 3).** Among all the selected districts, Kushtia, a high income district, will be affected negatively through the crop productivity loss under worst and medium climate change scenario by 2030. It can be observed that the gross region product loss is likely to be 3.68% and 1.09% under worst and medium scenario. Moreover, capital city Dhaka and high income district Chittagong might also expect a growth reduction of approximately 2.5% under the worst climate scenario. By 2030, it is likely that service or manufacturing sectors are likely to contribute greatly towards the growth of those districts. Also, the growth loss is expected to be minimal for districts like Meherpur with a projection of 1.4% under the worst climate scenario due to the diversity of crop production within that district. Among poor districts, Kurigram, the highest ranking poverty district will be affected negatively by the contraction of agricultural industries in general and paddy sector in particular. Finally, if the climate change impacts are optimistic, then it is likely to benefit both poverty stricken and least poverty stricken districts by 2030. Figure 1 also demonstrates the comparison of growth results for ten poverty stricken and ten least poverty stricken districts for worst, medium and optimistic climate induced crop productivity loss scenarios by 2030.

Table 3. Projections of percentage change in Gross District Domestic Products (GDDP) under different climate change scenarios by 2030

Poverty Stricken Districts	Sim1 (worst)	Sim2 (med)	Sim3 (optimistic)	Least poverty stricken districts	Sim1 (worst)	Sim2 (med)	Sim3 (optimistic)

Kurigram	-2.40	-0.71	0.92	Kushtia	-3.68	-1.09	1.41
Barisal	-3.06	-0.88	1.13	Noakhali	-2.45	-0.72	0.92
Shariatpur	-1.90	-0.57	0.76	Chittagong	-2.43	-0.71	0.93
Jamalpur	-2.62	-0.77	0.99	Dhaka	-2.50	-0.74	0.96
Mymensingh	-2.75	-0.80	1.03	Meherpur	-1.45	-0.44	0.59
Pirojpur	-2.41	-0.70	0.90	Bogra	-3.00	-0.87	1.12
Gaibandha	-2.80	-0.82	1.06	Naogaon	-2.92	-0.84	1.08
Chandpur	-2.60	-0.77	0.99	Manikganj	-3.14	-0.93	1.19
Rangpur	-2.67	-0.79	1.01	Narail	-2.18	-0.64	0.85
Satkhira	-2.87	-0.84	1.09	Rangamati	-2.64	-0.79	1.03

% change from the base case

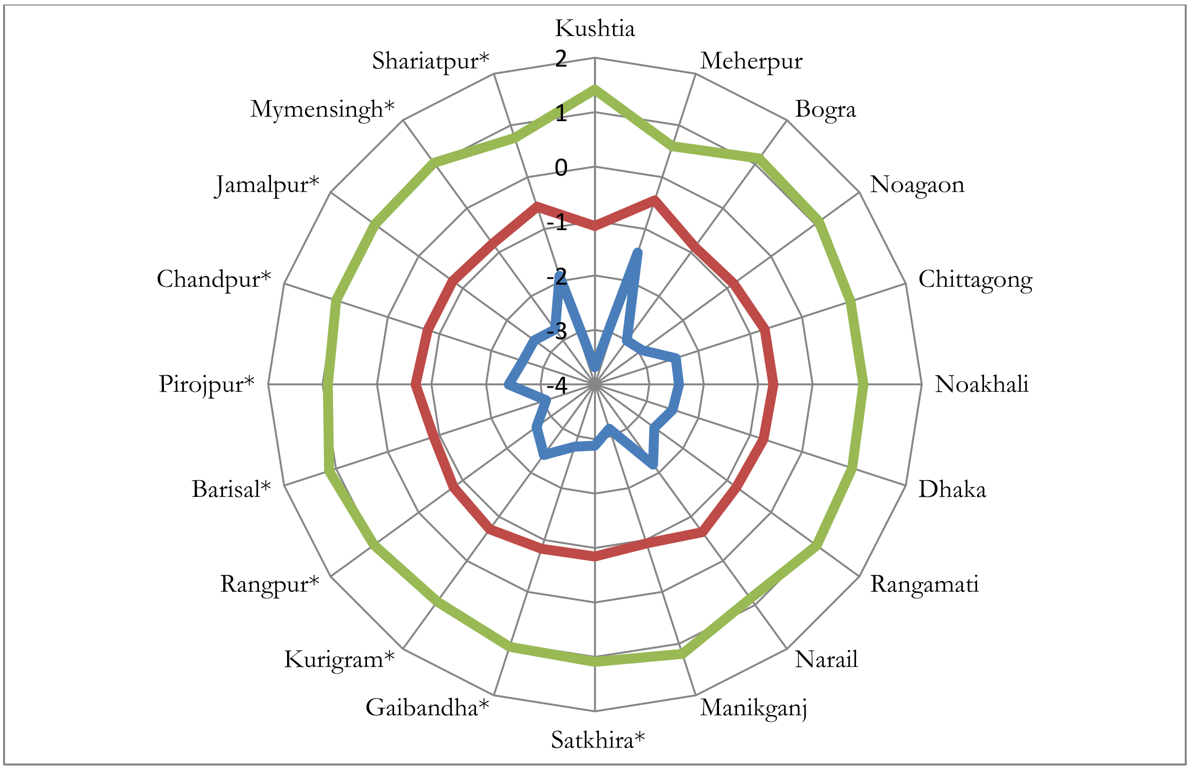

Figure 1. Comparison of growth for ten poverty stricken districts with star signs and ten least poverty stricken districts under worst, medium and optimistic climate induced crop productivity loss scenarios by 2030.

Worst scenario Medium scenario Optimistic scenario

It is evident from our model results that the extent of value added loss for agricultural sector varies substantially from one district to other, as described previously, depending on the proportion of different agricultural crops production among different districts and the resulting amount of crop loss due to climate change. For example, if we consider the paddy sector, it is evident that the value added loss is highest in Dhaka (7.41%) followed by Rangamati (6.93%), Chittagong (6.66%) and Kushtia (6.69%) compared to the poor districts like Kurigram (3.61%), Barisal (4.98%), Jamalpur (3.37%) and Mymensingh (4.27%) respectively. The key reasons behind that are the forward and backward linkage effects as well as the multiplier effects among different industries within a district. According to our model assumption, all agriculture and mining industries are local, whereas service and manufacturing sectors are national. Therefore, if any of those service or manufacturing sectors experience value added contraction nationally due to climate shocks, the results are similar for all 64 districts. Moreover, the growth contraction for those national industries can simultaneously create some multiplier effects for local commodity sectors through reducing output demand for those commodities. As the majority of the least poverty stricken districts are specialized in both manufacturing and service sectors compared to the poverty stricken districts, the value added loss is expected to be higher for some sectors among least poverty stricken districts. However, the contributions of manufacturing or service sectors towards the base year gross domestic product for those least poverty stricken districts are not large sometimes. Therefore, the current simulation results are consistent with the fact that most of the economic losses for the Bangladesh economy are also coming through the other value added sectors related to agriculture (Yu et al., 2010).

Table 4 and 5 represent the industry contribution towards the percentage changes of gross district domestic products (GDDP) under worst climate scenario by 2030. Surprisingly, the percentage change in regional GDP shows a very close pattern under worst and medium climate impacts scenario irrespective of poverty stricken or least poverty stricken districts. According to Tables 4 & 5, it is evident that the service sector contributes mostly towards growth contraction for both types of districts of Bangladesh resulting from medium to worst climate change scenario by 2030. On the one hand, among the poverty stricken districts, it can be observed that, paddy sector contributes the most towards the growth reduction in comparison to the other crop sectors (see table 4). This result can be expected as the majority of the poverty stricken districts are more or less specialized in paddy production. Among all those districts, paddy sector in Barisal district contributes mostly towards the GDDP loss followed by the manufacturing sector contribution. Similarly, for the highest poverty district namely, Kurigram, the major contributions are expected to come from paddy, jute and cotton sectors. In line with this, it can be observed that, jute and cotton industry is likely to contribute more than the manufacturing industries for districts like Shariatpur. On the other hand, among the least poverty stricken districts, manufacturing sector contributes significantly for industrial districts like Kushtia, Dhaka and Chittagong towards the percentage change in gross districts domestic production (see table 5). In addition, industries like jute, cotton and other crops also contribute greatly towards the growth loss. Moreover, if any service sector has any direct link with the manufacturing sector such as transports, the resulting impacts will also increase for those districts (Naranpanawa & Arora, 2014)[14]. However, districts like Naogaon, Bogra, Kushtia and Manikganj are likely to experience substantial growth reduction through the expected loss in paddy sector by -0.71%, -0.60%, -0.45% and -0.43% along with loss in manufacturing industries by -0.39%, -0.43%, -0.70%, and -0.31% respectively. Our predicted regional results are also consistent with the previous findings by (Kobayashi & Furuya, 2011) that Rajshahi regions (which include both Naogaon and Bogra districts) are likely to affect relatively more due to the paddy sector loss by

[14] In this paper, we are unable to identify the more disaggregated resulting impacts because of considering the manufacturing as well as service sectors as aggregated.

2050. Unlike other industries, vegetable as well as cotton and jute sectors contribute positively towards growth for Meherpur district even under worst climate scenario. This could be one of the key reasons behind the less growth loss condition of Meherpur district in Khulna division even under the worst crop loss scenario by 2030.

Table 4. Regional contribution to the percentage poverty stricken districts level GDP change under worst climate scenario by 2030

Industry Names	Mymensingh	Jamalpur	Shariatpur	Barisal	Pirojpur	Chandpur	Gaibandha	Kurigram	Rangpur	Satkhira
Paddy rice	-0.57	-0.38	-0.18	-0.68	-0.43	-0.30	-0.47	-0.37	-0.41	-0.42
Wheat	0.00	-0.02	-0.03	0.00	0.00	-0.01	-0.01	-0.05	-0.01	0.00
Cereal grains nec	0.00	0.00	0.00	0.00	0.00	0.00	-0.01	0.00	-0.01	0.00
Vegetables, fruits, nuts	0.00	0.01	0.05	0.00	0.00	0.00	0.00	0.01	0.00	0.00
Oil seeds	0.00	-0.05	-0.03	0.00	0.00	-0.01	0.00	-0.02	0.00	-0.01
Sugar cane	-0.02	-0.06	-0.01	-0.01	-0.01	-0.01	-0.04	0.00	-0.02	-0.01
Plant-based fibres	-0.14	-0.18	0.18	-0.12	0.00	-0.12	-0.21	-0.11	-0.16	-0.21
Crops nec	-0.03	-0.13	-0.22	-0.22	-0.03	-0.03	-0.02	-0.05	-0.07	-0.03
Cattle, sheep, goats	-0.03	-0.01	0.02	0.00	-0.01	-0.01	-0.04	-0.03	-0.03	-0.03
Animal Products nec	-0.02	-0.06	-0.01	-0.02	-0.02	-0.03	-0.02	-0.01	-0.02	-0.02
Raw milk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wool, silk-worm cocoons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Forestry	-0.02	-0.01	0.00	0.00	-0.01	0.00	0.00	0.00	0.00	-0.42
Fishing	-0.08	-0.03	-0.03	-0.20	-0.03	-0.14	-0.01	-0.03	-0.04	-0.09
Mining	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.01
Manufacturing	-0.26	-0.17	-0.15	-0.42	-0.21	-0.17	-0.24	-0.16	-0.22	-0.32
Services	-1.60	-1.56	-1.49	-1.42	-1.70	-1.80	-1.75	-1.60	-1.71	-1.35

% change from the base year

Table 5. Regional contribution to the percentage least poverty stricken districts level GDP change under worst climate scenario by 2030

Industry	Kushtia	Narail	Meherpur	Bogra	Naogaon	Noakhali	Chittagong	Rangamati	Dhaka	Manikganj
Paddy rice	-0.45	-0.35	-0.16	-0.60	-0.71	-0.33	-0.20	-0.10	-0.02	-0.43
Wheat	-0.05	-0.03	-0.18	0.00	-0.03	0.00	0.00	0.00	0.00	-0.01
Cereal grains	-0.01	0.00	-0.01	-0.01	0.00	0.00	0.00	0.00	0.00	-0.01
Vegetables, fruits, nuts	0.00	0.01	0.05	0.00	0.00	0.00	0.00	-0.01	0.00	0.00
Oil seeds	-0.01	-0.05	-0.06	-0.02	-0.03	0.00	0.00	-0.01	-0.01	-0.12
Sugar cane	-0.07	-0.03	-0.04	-0.01	-0.02	0.00	0.00	0.00	0.00	-0.05
Plant-based fibres	-0.64	0.18	0.64	-0.25	-0.14	0.00	0.00	-0.07	-0.02	-0.25
Crops nec	-0.29	-0.30	-0.21	-0.04	-0.03	-0.05	-0.05	-0.07	0.00	-0.28
Cattle, sheep, goats	-0.05	0.03	0.05	-0.02	-0.02	0.00	-0.01	-0.01	0.00	-0.04
Animal Products nec	-0.01	-0.01	-0.01	-0.02	-0.02	-0.03	-0.01	-0.01	0.00	-0.01
Raw milk	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Wool, silk-worm cocoons	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Forestry	0.00	0.00	0.00	0.00	0.00	-0.07	-0.08	-1.06	0.00	0.00
Fishing	-0.02	-0.01	-0.01	-0.06	-0.09	-0.17	-0.02	-0.02	0.00	-0.11
Mining	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.01	0.00
Manufacturing	-0.70	-0.24	-0.15	-0.43	-0.39	-0.17	-0.31	-0.22	-0.52	-0.31
Services	-1.44	-1.40	-1.36	-1.56	-1.47	-1.66	-1.78	-1.08	-1.95	-1.56

% change from the base year

However, when we consider the average income loss due of poor population to climate change within poverty stricken and least poverty stricken districts, then results predict that the average percent change of income loss for former districts are likely to be greater compared to the later districts under both worst and medium scenarios[15]. If the effect of global warming will become worst then the percentage change of average income loss of the poor population from ten poverty stricken districts is likely to be 0.81% by 2030. However, the loss is relatively lower of -0.14% for the ten least poverty stricken districts. Similarly, for the medium climate scenario the income loss for poverty stricken districts is 0.25%. However, the average income losses for ten least poverty stricken districts are 0.04% which is near to zero. Our result supports the previous findings by (Hertel et al., 2010) that climate change affects Bangladesh more negatively because of its large poor population. Figure 2 depicts the percentage change of average income loss due to climate change by 2030 for twenty selected districts of Bangladesh. It is projected that all those poverty stricken districts will experience greater income loss due to worst and medium crop productivity loss scenario compared to least poverty stricken districts by 2030. Further, districts like Barisal, Kurigram are likely to experience maximum income loss due to the near future climatic shocks; however, districts like Kushtia, Meherpur might expect relatively minimum income loss after 14 years.

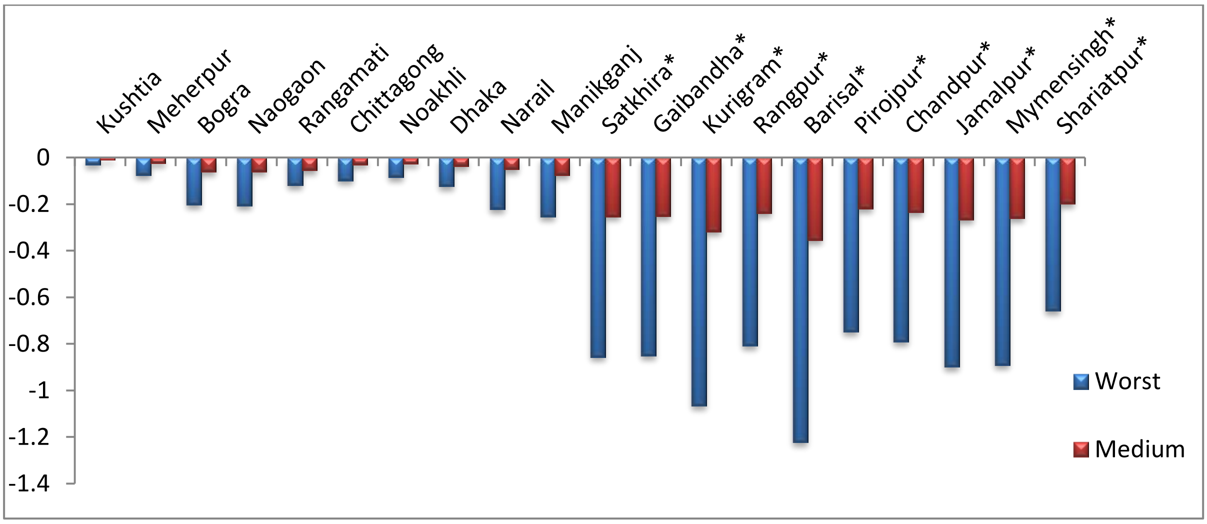

Figure 2.Comparison of average income loss of poor population between poverty stricken and least poverty stricken districts in Bangladesh under the worst and medium crop productivity loss due to climate change by 2030

[15] If the percentage of poor population of district $A = X^1$ and the simulated percentage change loss of $GDDP = Y^1$, then the percentage change of income loss for poor population in district $A = Y^1 * (X^1/100)$. (Assumption: any income gain or loss after simulation is equally distributed within that district).

The overall results suggest that the extent of loss in national as well as district level GDP of Bangladesh differs due to the national crop productivity loss as a near future consequence of climate change. Although global warming and other climate impacts are responsible for reducing the national and districts level economic growth, however, the growth disparity is not likely to be very significant among 64 districts of Bangladesh by 2030 compared to the base year 2007. The key reason behind that is the difference in sectoral contribution across different districts towards that particular district's GDP. The growth loss is likely to be greater for those least poverty stricken districts where the contributions from the manufacturing, service sectors as well as agriculture sector is higher towards that district's GDP. However, for majority of the poverty stricken districts, the main reasons of growth loss are due to the loss in agricultural sector. Therefore, the growth losses are likely to be balanced between poverty stricken and least poverty stricken districts. As such, and the growth disparity between the two types of districts are not likely to be much dispersed. However, the average income loss of poor population will be greater for those poverty stricken districts than those least poverty stricken districts under the worst and medium climatic impacts scenarios. It is also evident that all twenty selected districts are likely to be negatively affected through the national agriculture loss due to climate change by 2030. Since majority of the poverty stricken districts are agriculture intensive, it can be expected that the growth contractions for those districts are comparatively higher than those districts, experiencing less poverty. These findings will also support the fact that climate change might accentuate the existing food insecurity problem in the near future within Bangladesh (Yu et al., 2010).

5. Conclusion and policy implications:

This study aims to identify the near future economic impacts of climate change for the 64 in Bangladesh districts by developing a static "top-down" multi-regional CGE model. Three climate change scenarios were simulated for 2030 under the standard neoclassical assumptions based on the Australian ORANI-G CGE model.

There are many contributions of this study. Firstly, the study results suggest that the policymakers in Bangladesh should design the district specific adaptation programme in order to adapt to the near future impacts of climate change. Secondly, poor population in relatively more vulnerable districts must require necessary financial or skilful assistance from not only the central organisation but also from the non-governmental organisations (NGO). Finally, the results further support the need for regional policy analysts and policy makers to give special attention to specific districts which have already started facing the seasonal food insecurity problem (for example: Northern "Monga" prone regions like Kurigram district, (for e.g, see Ahamad et al., 2013).

Overall our results imply that, if the climate conditions become moderate to worst by 2030 then that will have significant negative impacts on the national macroeconomic environment in Bangladesh through lowering the country's real GDP, average real wages, and real household consumption. Even if our model results have projected that the percentage change in gross regional products of most of the districts will be declining, climate change alone would not be responsible for widening up the growth disparities among 64 districts in Bangladesh by 2030.

Based on the above general equilibrium analysis, it is also evident that the average income loss of the poor population in poverty stricken districts is greater than the average income loss in the least poverty stricken districts. Though, the percentage change of average income loss of the poor population under the medium and worst climate conditions is not very alarming, it might have substantial impacts on the district level poverty in a developing country like Bangladesh. As agriculture is the central sector in most of the backward districts in Bangladesh and forms the key livelihood for the majority of the population, this study will provide the projections of how the macroeconomic conditions of Bangladesh will affect due to agricultural loss by 2030. According to Akter and Basher (2014), it is essential to take into account the interregional growth disparities and poverty dynamics of Bangladesh in order to propose the national level strategies to combat external shocks. Therefore, the study results will not only guide the policy makers of Bangladesh in particular, but also the South Asian countries in general in formulating and analysing the impacts of national and districts level policies towards climate change adaptation after 14 years later. Further, these findings would also support the Bangladesh Government in designing district specific programs towards achieving the millennium development goals by reducing the poverty and regional disparity in the face of the future climate change threat.

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