

AN ECONOMY-WIDE ANALYSIS OF CLIMATE CHANGE IMPACTS ON AGRICULTURE AND FOOD SECURITY IN BANGLADESH

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Bangladesh is one of the most vulnerable countries to climate change (CC) with higher temperatures reducing crop yields and sea level rise decreasing arable land supply. The Government of Bangladesh aspires to offer its people a comparable standard of living to that of middle-income countries by 2021. Bangladesh's population will reach 247 million by 2050 and GDP is projected to grow annually by 7.9%. With increasing population density, greater demand for resources, and CC impacts, adaptation and mitigation strategies will be required for agricultural output to meet growing food demand. We develop a dynamic computable general equilibrium model linked with a food security module to explore CC impacts on agriculture and food security. Although CC impacts had a relatively small effect on GDP, reducing it by \$29,925 million Taka (−0.11%) by 2030, agricultural sector impacts were felt more acutely, reducing output by −1.23%, increasing imports by 1.52%, and reducing total caloric consumption by 17%, with some households remaining underfed due to inequitable food distribution. Evidence generated here can guide policy to ensure economic growth contributes to meeting national development and food security targets.

Keywords: Climate change; food security; food self-sufficiency; agriculture; computable general; equilibrium model; Bangladesh.

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Highlights

- Climate change impacts on the Bangladesh economy will reduce GDP by 29,925 million Taka (−0.11%) by 2030.
- Agricultural output will fall by −1.23% and domestic food consumption will be more dependent on imports, increasing by 1.52% by 2030.
- Total caloric consumption will be reduced by 17%, the nutritional composition of some households' diet will worsen and some will still go hungry due to distributional issues.

1. Introduction

Bangladesh's climate is subtropical monsoonal exhibiting high seasonal variation in precipitation and temperature (Ali, 2002). Summers are hot and wet, while winters can be quite dry, resulting in drought in some regions (Yu et al., 2010). During the monsoon season, up to two-thirds of the country may be inundated, and cyclones and storm surges occur frequently. In a country where water would seem to be abundant, water resources are under great stress (Shahid and Hazarika, 2010).

Sources of water for drinking, irrigated agriculture, and industry are under real threat from saline intrusion in the southwestern parts of the country, the ingress of polluted surface waters, and arsenic contamination of shallow groundwater (Chowdhury, 2010). Major urban centers are already challenged to meet demand while population growth and economic development will put additional strain on water resources.

Exacerbating these challenges, Bangladesh is one of the most vulnerable and exposed countries to climate variability and change. Temperatures are projected to rise implying greater crop evapotranspiration (Yu et al., 2010). Impacts on agricultural output will be determined by how precipitation may compensate for increased evapotranspiration, the carbon dioxide fertilization effect, the potential to increase irrigation of affected crops and bring new areas into agricultural production (Cline, 2007). Sea level rise is also projected to reduce the supply of arable land, increase storm surges, and affect settlement patterns, fisheries, and tourism (IWM and CEGIS, 2007). Increased surface water inflows into Bangladesh and potentially greater monsoonal precipitation will increase flooding risk during the wet season.

The Government of Bangladesh aspires to offer its people a comparable standard of living to that of middle- and high-income countries by 2021 (Planning Commission, 2010). The Government has well-defined targets and strategies to achieve this aim and places significant emphasis on achieving food security and reducing poverty. Bangladesh's population is increasing at an Average Annual Growth Rate (AAGR) of 1.29% and will reach 247 million by 2050 (BIDS, 2013b). Gross domestic product (GDP) is projected to grow on average at 7.9% until 2050 (BIDS, 2013a). This projection is good news since the World Bank has assessed that Bangladesh would

need to grow between 7% and 8% per annum if it is to achieve its development ambitions (World Bank, 2011).

Considering projected economic and population growth, we develop a recursive dynamic computable general equilibrium (DCGE) model to evaluate how climate change (CC) may affect agriculture and Bangladesh's economy overall. Focusing on the *access* pillar of food security,¹ we consider CC impacts on food production and households' ability to purchase food. Following the direct caloric intake approach and the national food poverty line of 2122 kcal, we develop a food security module and use outputs of the DCGE to evaluate if this food security target is met for various household categories.

DCGE models provide advantages over other analytical frameworks offering a consistent theoretical lens through which socioeconomic and environmental trade-offs are analyzed. DCGE models have a high degree of explanatory power where inter-sectoral linkages and resource constraints may be binding (Banerjee and Alavalapati, 2010). Static one-period models can inform on orders of magnitude and direction of effect of a policy or environmental shock in the short or long-run while dynamic models enable a more precise specification of time, illustrating economic transition paths, and short and long-term costs and gains (Cattaneo, 1999).

This study builds on the work of Yu *et al.* (2010) by considering how CC impacts on the agricultural sector could affect household food security. Furthermore, this analysis customizes the most recent social accounting matrix (SAM) for Bangladesh, developed by Khondker and Raihan (2011) reflecting recent structural changes in Bangladesh's economy. Two core scenarios are implemented. In the first scenario, the baseline forecast, Bangladesh's economy is projected from the base year of 2006/2007 to 2030 imposing growth projections based on historical tendencies and in the absence of CC. In the second scenario, the CC scenario, we impose assumptions on the model that reflect current understanding of CC impacts (Huq, 1999; IWM and CEGIS, 2007; Yu *et al.*, 2010). The impacts we simulate are (i) sea level rise and increased annual flooding reducing arable land supply, and; (ii) increased crop evapotranspiration resulting from higher than average temperatures. The differences in macroeconomic indicators, output, and income between the baseline forecast and the CC scenario reflect the effect of CC on Bangladesh's economy.

This paper is organized as follows. Following this introduction, the research methods are presented, providing an overview of the DCGE approach, a preliminary exploration of the core data source, the SAM, and the DCGE workflow design. Section 3 describes the CC scenarios and Sec. 4 presents the results of the scenario analysis. Section 5 develops a food security module to evaluate CC impacts on food

¹Food security was defined in 1996 at the World Food Summit as a situation "when all people at all times, have physical, social and economic *access* to sufficient, safe and nutritious food to meet their dietary needs and food preferences for an active and healthy life" (FAO, 1996). Building on this definition at the World Summit of Food Security in 1999 the four pillars of food security were established as availability, *access*, utilization and stability, with nutrition an integral dimension of the system (Ecker and Breisinger, 2012).

security. The final section provides a discussion on the policy implications of the findings.

2. Methods

2.1. A DCGE approach

The model developed here is based on the International Food Policy Research Institute's (IFPRI) Standard CGE Model and Robinson and Thurlow's dynamic extension to the model (Robinson and Thurlow, 2004). This model is implemented in the General Algebraic Modeling System (GAMS) and solved as a mixed complimentary problem using the PATH solver. This model was developed by IFPRI to facilitate the use of CGE models in developing countries (Lofgren *et al.*, 2002). Although this model is thoroughly documented in Lofgren *et al.* (2002) and Robinson and Thurlow (2004), the basic model structure is presented here.

The DCGE model describes the behavior of agents in their economic environment; it is a system of equations describing the utility maximizing behavior of consumers, profit maximizing behavior of producers, and the equilibrium conditions and constraints imposed by the macroeconomic environment. Agent behavior is represented by linear and nonlinear first-order optimality conditions and the economic environment is described as a series of equilibrium constraints for factors, commodities, savings and investment, the government, and rest of the world (RoW) accounts (Lofgren *et al.*, 2002). The model may be broken into a series of blocks, namely: production, factor markets, institutions, commodity markets, and macroeconomic balances. These model blocks are discussed in turn.

The model's structure enables a given activity to produce more than one commodity, while any one commodity may be produced by more than one activity. Firms are price takers and minimize costs subject to nested technological constraints. At the top of the nest, sectoral output is determined by combining value-added with intermediate consumption through a fixed share, Leontief production function. Composite labor is a constant elasticity of substitution (CES) function of various types of labor indicating imperfect substitution between types of labor. Composite capital and land are also formed in this way. Value-added is created by a CES function of factors (labor, capital, and land) where firms employ factors until the value of the factor's marginal product is equal to the factor price. Goods and services consumed as intermediate inputs are treated as perfectly complimentary with aggregate intermediate consumption formed by a Leontief function.

Households receive income from labor, capital, land, and transfers from other agents including remittances from abroad. Factor income is apportioned to households in fixed shares while income from transfers is the sum of all transfers for each household category. Households pay direct taxes and make transfers to the government. Disposable household income is equal to household income net of transfers, taxes, and savings. Household savings are a linear function of disposable income.

Firms receive income from returns to capital and transfers from other agents. Firms pay income tax and also save. The government receives income from income tax paid by firms and households, indirect taxes on goods and services, capital taxes, import duties, production taxes on industries, payroll taxes from labor, export taxes, and income from capital and transfers.

Income taxes for firms and households are a linear function of their total income. The RoW receives income from the sale of imports, returns to capital, and transfers while foreign spending consists of export purchases and transfers to agents in the domestic economy. Transfers to households and firms are treated as proportional to their disposable income while household transfers to government are treated as a linear function of total income.

Goods and services are demanded by households, the government, investment, and as transport and trade margins. Households have a Stone–Geary utility function, with a linear expenditure system (LES) describing household consumption. In a LES, households use their income to first consume a minimum level of subsistence goods and services. With the supernumerary income remaining, households purchase goods and services according to a linear relationship between income and consumption. LES differ from CES functions in that LES functions have nonunitary income elasticities between all pairs of goods (Annabi *et al.*, 2006) enabling flexibility with regards to substitution possibilities in response to changes in relative prices (Decaluwé *et al.*, 2010).

Investment demand is composed of gross fixed capital formation (GFCF) and changes in inventories. GFCF is endogenous with total investment expenditure balanced by the savings and investment constraint where savings is endogenous. Inventory changes are exogenous in the model and fixed in volume. Investment in goods and services occurs in fixed shares where investment in a commodity is inversely related to its price. Government expenditures for a given budget also follow this logic.

The small country assumption is made and import and export prices are exogenous. A constant elasticity of transformation (CET) function describes how industry output responds to changes in prices. This functional form implies that an industry may reorganize production in response to changes in prices, though they cannot perfectly switch from the production of one commodity to another. Industries allocate output to domestic and foreign markets based on the assumption that the goods destined to one market are different from those destined to another market. This assumption is operationalized through a CET function. Domestic producers are able to capture greater foreign market share by reducing their price relative to the exogenous world price for that good or service. This specification enables changes in world demand to be simulated. To reflect heterogeneity in goods and services with regards to their origin, goods, and services consumed domestically are aggregate goods composed of domestically produced and imported goods.

Model dynamics specify adjustments to account for endogenous investment and exogenous population and labor force growth, depreciation, and changes in total factor

productivity. Capital is sectorally allocated as a function of the rate of capital depreciation and the differential in profits between sectors from the previous period (Robinson and Thurlow, 2004). Endogenous adjustments to account for capital accumulation and exogenous adjustments to population, labor force, and total factor productivity are discussed in turn.

Capital supply is based on the previous period's capital stock and allocation of investment spending. Investment is carried out in proportion to a sector's share in economy-wide capital income and is adjusted by the ratio of a sector's rate of profits and the economy-wide average rate of profit. This specification implies that a sector with higher than average profits will receive a larger share of investment than its average share in aggregate capital income.

Population growth has a direct and positive impact on household consumption expenditure. The quantity of income-independent consumption increases at the same rate as population growth. The level of minimum household consumption expenditure also increases proportionally with population growth. Growth affects average rather than marginal consumption demand implying that new consumers share the same preferences as existing consumers. The subsistence consumption of commodities is adjusted upwards by the rate of population growth.

With flexible nominal wages and full employment, the between period levels of labor supply increase according to the rate of labor force growth, which grows at the same rate as the population. Total factor productivity is exogenous and determined by a technological parameter introduced in the model equations for the calculation of the quantity of aggregate value-added. The efficiency parameter in the CES value-added function is shifted upwards by total factor productivity growth.

There are three macroeconomic balances in the model: the government current account balance, the current account of the balance of payments, and the savings and investment balance. Decisions regarding macroeconomic balances in the model are known as closure rules and are necessary to maintain a balanced economic environment. The choice of closure rules may have a significant impact on model behavior (Dewatripont and Michel, 1987).

The balanced closure used in this study is recognized to provide a more accurate representation of how real economies have behaved (Lofgren *et al.*, 2002). In this closure, modeling experiments are conducted in a macroeconomic environment where investment and government consumption shares are fixed while their quantities are flexible. Nominal absorption shares of investment and government consumption are fixed at their base year levels. For factor closures, labor, capital, and land are fully employed and mobile between sectors. A flexible real exchange rate is chosen for the RoW closure while the government closure fixes direct tax rates enabling flexible government savings. The consumer price index is chosen as the numeraire.

2.2. SAM for Bangladesh (2006/2007)

The core data source for a DCGE is the SAM. A SAM is a statistical representation of an economy which describes payments and receipts between economic agents, factors, and intermediate and final goods and services. We customize the most recent SAM available for Bangladesh. Developed by [Khondker and Raihan \(2011\)](#), this SAM was used to assess the economic implications of Bangladesh's 6th five year plan for development ([Khondker and Raihan, 2011](#)). The new SAM is based on an input–output table for 2000, as well as the most up to date information available on production and consumption. The base year of 2006/2007 was chosen since it is the most recent year for which comprehensive data on Bangladesh's economy was available. Furthermore, it was considered a relatively normal year, unaffected by the recent global economic crisis and other shocks such as severe weather events. The SAM construction procedures are documented in detail in [Khondker and Raihan \(2011\)](#).

We customize the SAM to focus on the agricultural sector. The economy is aggregated to 27 sectors/commodities, 14 of which are related to agriculture and food production (Table 1).

The SAM contains skilled (\geq class level of 10) and unskilled labor (class 0 to 9) categories, capital, and land as factors of production. There are 11 institutions, eight of which are households, six rural and two urban. Households are disaggregated according to the Household Income and Expenditure Survey (HIES) classification system. The HIES has been conducted in Bangladesh since 1973–1974, collecting data on income, expenditure, consumption, savings, housing, education, employment, and many other indicators. Table 2 details the characteristics of the households in the model. Rural agricultural households are described according to their land endowments; nonagricultural households are distinguished by whether or not they are

Table 1. Sectors in the 2006/2007 Bangladesh SAM.

Agricultural sectors	Nonagricultural sectors
1. Rice	15. Forestry
2. Wheat	16. Oil
3. Other grains	17. Water and electricity
4. Potato	18. Housing
5. Vegetables	19. Health
6. Pulses	20. Education
7. Other crops	21. Public administration
8. Fruit	22. Manufactured goods
9. Livestock	23. Construction
10. Poultry	24. Mining and gas
11. Fish	25. Trade
12. Milled rice	26. Transport
13. Milled grain	27. Services
14. Processed food	

Table 2. Household endowment categories.

Household type
1. Landless (0 ha)
2. Marginal (≤ 0.198 ha)
3. Small agricultural (0.202 to 1.008 ha)
4. Large agricultural (agricultural > 1.012)
5. Rural nonagricultural poor
6. Rural nonagricultural nonpoor
7. Urban educated
8. Urban less educated

poor. The two urban households types disaggregated by level of education with less educated households possessing less than or equal to 8th class education and higher educated households possessing greater than 8th class education. The remaining three institutions are the government, firms, and the RoW. The final two accounts in the SAM are public and private investment, and inventories.

3. Scenario Design

The first scenario is the baseline scenario which modeled Bangladesh's economy from the base year of 2006/2007 to 2030 assuming historical tendencies and in the absence of CC. Such factors, productivity, yield, and the overall economy followed a balanced growth path. The second scenario simulated projected CC impacts and was informed by future climate scenarios and agricultural crop modeling conducted by Yu et al. (2010). Estimates of sea level rise were based on IWM and CEGIS (2007).

Estimates for future temperature and precipitation changes from Yu et al. (2010) were based on analysis of 16 global circulation models for A1B, A2, and B1 emissions scenarios. Results indicated positive temperature changes for every experiment and every month with a median warming of 1.1°C by 2030. With regards to precipitation by 2030, it was not possible to discern clear trends, though by 2050, some models predicted a trend of increased annual and wet season precipitation. Median estimates predicted precipitation may increase up to 4% over the baseline by 2050 (Thurlow et al., 2011).

Yu et al. (2010) used the Crop Environment Resource Synthesis (CERES) modeling system to estimate CC impacts on crop output. The authors reported the joint impact on crop output due to changes in temperature and precipitation, coastal and inland flooding, and a carbon dioxide enrichment effect on crop yields. In the CC scenario, we used an output-weighted average of median production changes for the A2 and B1 emissions scenarios and applied these linearly over the period of analysis. Median production percentage changes were estimated as -0.25%, -0.37%, -3.06%, and 2.05% for *aus*, *aman*, and *boro* rice varieties and for wheat, respectively (Yu et al.,

2010). This weighted average for rice output amounted to a -1.8% change in production by 2030.

Estimates of sea level rise were provided by IWM and CEGIS (2007). Sea level rise of 15 and 27 cm were estimated to result in a loss in agricultural land of 1.5% and 2.5%, respectively (IWM and CEGIS, 2007). Following Thurlow *et al.* (2011) and considering an average rate of expansion of agricultural land of 1.0% per year, we implement an evenly distributed loss of 1% of agricultural land over the period of analysis.

4. Results

Table 3 provides an overview of Bangladesh's economy in the base year. GDP in 2006/2007 was over 4.7 trillion Bangladesh Taka (BDT). The investment share of GDP accounted for over 25% of GDP while imports surpassed exports by more than 327 billion BDT.

Rural landless households spend 47% of their food budget on milled rice while urban educated households spend 26%. Expenditure shares on other crops show that wealthier households spend a smaller proportion of their income on food staples such as milled rice and instead consume more meat protein and a considerably greater share of processed food.

To facilitate analysis of the relative impacts on macroeconomic indicators, results reported in Table 4 are the differences in AAGR between the CC scenarios and the baseline scenario. All macroeconomic indicators, with the exception of government consumption, grew faster in the baseline. Introducing the climate shock, the AAGR of GDP grew slower by -0.0047% or by -0.11% in 2030. Real GDP at market prices (gross value-added less intermediate consumption) in the base year was 4.70 trillion BDT and grew to 27.55 trillion BDT by 2030. With CC, GDP in 2030 was 29,925 million BDT less, equivalent to 6313 million BDT in net present value terms (7% rate of discount). The CC impact on GDP was equivalent to approximately 11% of total

Table 3. Bangladesh macroeconomic aggregates (2006/2007).

GDP component	Millions of Taka
1. Private consumption (<i>C</i>)	3,561,043
2. Public consumption (<i>G</i>)	261,056
3. Investment (<i>I</i>)	1,229,898
Private	939,567
Public	257,258
Change in stock	33,073
4. Exports (<i>X</i>)	934,403
5. Imports (<i>M</i>)	1,261,628
GDP at market prices	4,724,772

Table 4. Decomposed climate shock percent deviation from baseline in AAGR.

Macroeconomic indicator	Sea level rise (%)	Paddy yield (%)	Wheat yield (%)	Joint impact (%)
Private consumption	-0.0036	-0.0130	0.0001	-0.0165
Fixed investment	0.0057	0.0071	0.0001	0.0129
Government consumption	0.0000	0.0000	0.0000	0.0000
Exports	0.0125	0.0168	-0.0001	0.0293
Imports	0.0120	0.0162	-0.0001	0.0282
GDP	0.0001	-0.0049	0.0001	-0.0047

government expenditure in 2006/2007. Private consumption grew slower by -62,804 million BDT (-0.0165%) by 2030. Fixed investment grew faster by 32,879 million BDT (0.0129%) by 2030, as did exports and imports (0.0293% and 0.0282%, respectively, each increasing by 65,800 million BDT by 2030).

Equation (1) is the GDP equation, where C is private consumption, I is investment, G is government expenditure, X are exports and M are imports. In the CC simulation, the positive impact of faster export and investment growth was insufficient to offset slowed growth in consumption and increased import growth, resulting in slightly slower GDP growth.

$$GDP\downarrow = C\downarrow + I\uparrow + G + X\uparrow - M\uparrow. \tag{1}$$

Table 5 provides an overview of the joint impact of climate shocks on trade, output, and prices. Figures in bold indicate slowed growth in the baseline. Domestic agricultural output in the baseline contracted for wheat, other grains, vegetables, pulses, and fruit. The CC impact slowed growth in paddy, milled rice, and potato output while

Table 5. Deviation in AAGR from baseline due to climate shock for trade, output, and prices.

Commodity	Imports (%)	Exports (%)	Domestic output (%)	Composite output (%)	Composite price (%)
Wheat	-0.0122	0.1344	0.0913	-0.0069	-0.0696
Other grains	0.0385	-0.2021	-0.1314	-0.0185	-0.0488
Potato	0.1105	-0.1584	-0.0793	-0.0354	-0.0192
Vegetables	0.0233	-0.2508	-0.1702	-0.0164	-0.0546
Pulses	0.0362	-0.2511	-0.1666	-0.0180	-0.0497
Fruit	0.0348	-0.3171	-0.2136	-0.0147	-0.0513
Other crops	0.0378	-0.1326	-0.0825	0.0005	-0.0554
Livestock	0.1355	-0.1158	-0.0419	-0.0408	-0.0090
Poultry	0.0441	-0.0305	-0.0085	-0.0074	-0.0506
Fish	-0.0156	-0.0037	-0.0072	-0.0072	-0.0706
Milled rice	0.3015	-0.3118	-0.1314	-0.0760	0.0580
Milled grain	-0.0178	-0.0015	-0.0063	-0.0064	-0.0716
Processed food	-0.0066	-0.0226	-0.0113	-0.0110	-0.0643

Table 6. Deviation in AAGR from baseline due to climate shock for household income.

Household income	Sea level rise (%)	Paddy yield (%)	Wheat yield (%)	Joint impact (%)
Landless	-0.0209	-0.0486	0.0002	-0.0694
Marginal	-0.0179	-0.0442	0.0003	-0.0619
Small farmers	-0.0156	-0.0402	0.0004	-0.0557
Large farmers	-0.0115	-0.0332	0.0005	-0.0445
Rural nonagricultural poor	-0.0190	-0.0453	0.0003	-0.0642
Rural nonagricultural not poor	-0.0171	-0.0451	0.0003	-0.0621
Urban less educated	-0.0226	-0.0482	0.0003	-0.0707
Urban educated	-0.0181	-0.0468	0.0003	-0.0648

output for other commodities contracted further. Overall, domestic agricultural output declined by -1.23% by 2030. Composite output for all agricultural commodities (a composite of domestically produced and imported agricultural goods) grew in the baseline. CC resulted in slower growth, with the exception of *other crops*. Agricultural prices in the baseline fell for wheat, livestock, poultry, fish, milled grain, and processed food. The climate shock further depressed prices for wheat, livestock, poultry, fish, milled grain, and processed food, and slowed growth in the case of other grains, potato, vegetables, pulses, fruit, and other crops. The price of paddy and milled rice grew faster with CC.

All agricultural imports grew in the baseline. CC caused faster import growth for most commodities, with the exception of wheat, fish, milled grain, and processed food. In 2030, agricultural imports were 1.52% higher with CC. Relative to the increased rates of growth of other agricultural commodities, the impact on milled rice imports was the greatest (0.3015%). In the baseline, export growth of wheat, other grains, potatoes, vegetables, pulses, fruit, other crops, and milled rice slowed. With CC, exports contracted further across the board with the exception of wheat and in 2030, agricultural exports were -0.28% lower.

For all household categories, income grew in the baseline; CC impacts slowed this growth somewhat (Table 6). Large farmers appeared to be the most insulated from climate shocks, with the urban less educated the most vulnerable.

With regards to factors, as land became scarcer as a function of sea level rise and increased demand for agricultural commodities, the joint impact of the climate shock led to a 0.0231% increase in the AAGR of land rentals over the baseline. For labor and capital, the climate shock slowed AAGR by between -0.0718% and -0.759% for skilled and unskilled labor, respectively and by -0.0743% in the case of capital.

5. Food Security and Poverty

5.1. Analytical approach

In this analysis, we applied the direct caloric intake method to evaluating food security using a food poverty line of 2122 kcal/day/person and a food security

module. This food poverty line has been in use for many years in Bangladesh and is the standard used by the Bangladesh Bureau of Statistics. The food poverty line corresponds to the minimal nutritional requirements to maintain a healthy life. A key advantage of this approach is that it controls for differences in household purchasing power through time (Ravallion and Sen, 1996). Our analysis utilized the latest HIES data for 2010.

The first step of the analysis involved specifying a fixed food bundle which satisfied the caloric requirement of the poverty line. Similar to Ravallion and Sen (1996), the food bundle was specified to contain 10 food items: rice, potato, vegetables, pulses, fruit, livestock, fish, grains, poultry, and processed food (Ravallion and Sen, 1996). Next, for each household category from the SAM, expenditures on the 10 food bundle items in the base year were extracted and divided by their price per kilogram to obtain the quantity of each food item consumed.

A caloric conversion table was used to determine the caloric consumption per household category. This caloric intake was compared to the minimum requirement for each household category, which was calculated as the product of the 2122 kcal/person/day food poverty line and the population of each household category. Comparing these two figures, whether or not a household category had a caloric deficit or surplus was deduced. Calculations were performed in the same manner for the results from the baseline forecast and the CC scenario for the year 2030.

For these calculations, we assumed households had equal *access* to food within household categories (i.e., all households within a household category consume the same number of kcal), and the proportion of the population in each household category remained constant over the period of analysis. Furthermore, the landless and marginal households were aggregated into a landless/marginal category and the rural nonagricultural poor and rural nonagricultural nonpoor were aggregated into a nonagricultural rural category.

For purposes of comparison, household consumption for a subset of the food bundle in the base year of 2007 was compared with the desirable caloric composition as determined by the World Food Programme. Taking urban less educated households as a test case, the actual and desirable caloric composition is reported in Table 7. This household category is food insecure in the base year.

This urban less educated household category consumed a greater proportion of rice (63% versus 62%), grains (17% versus 5%), and potatoes (7% versus 3%) than desirable. More costly food items such as vegetables, pluses, fruits, and meat were estimated to be consumed at a proportion less than what a balanced diet demands.

5.2. Food security results

The landless/marginal, small, and large farming households, and both urban educated and urban less educated households had a caloric deficit in the baseline. Nonagricultural rural households had a caloric surplus. In the absence of the CC shock, by

Table 7. Food intake in the base year, 2030 with CC and desirable food intake.

Food item	Actual kcal intake ^a	% total	2030 kcal intake with CC ^a	% total	Desired kcal intake ^b	% of desired
Rice	532	63	898	51	1,247	62
Grain	147	17	487	28	105	5
Potato	62	7	92	5	59	3
Vegetables	24	3	48	3	165	8
Pulses	23	3	42	2	136	7
Fruit	9	1	14	1	42	2
Animal-based food	30	4	92	5	237	12
Processed food	23	3	77	4	34	2
Total	850	100	1,750	100	2,025	100

^aModel results.

^bFollows the World Food Programme’s food composition recommendations.

2030 the situation was much improved as a result of sustained economic growth, with all household categories meeting the minimum caloric requirements. When the CC shock was imposed, however, urban less educated households became calorie deficient. Considering all household categories together, in the base year there was a caloric deficit of 46 billion kcal. In 2030 in the baseline forecast, there was a surplus of over 516 billion kcal. With CC, the surplus was reduced to 355 billion kcal.

Figure 1 presents the percentage deficit or surplus with regards to the minimum caloric requirement of 2122 kcal. In the baseline in 2007, nonagricultural rural households were the most food secure with an intake of 63% above the minimum while the urban less educated were the most food insecure with intake 60% below the minimum. Next were the small farmers, urban educated and landless/marginal households falling short of the minimum by –36%, –33%, and –32%, respectively. In the baseline in 2030, urban less educated households just met the minimum while the rest surpassed it.

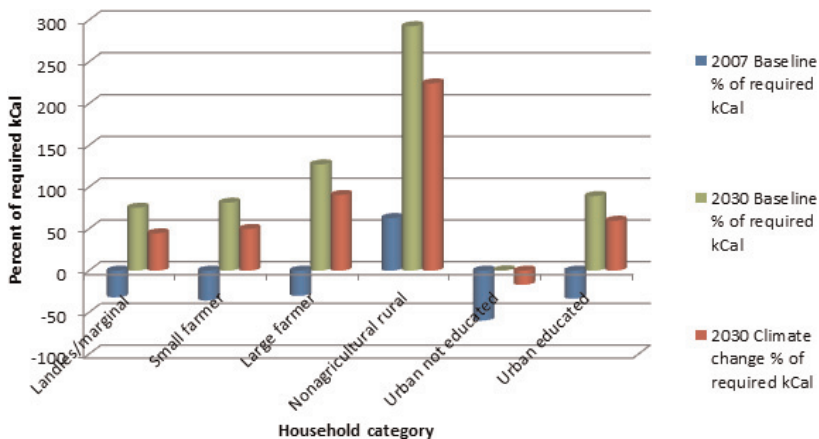


Figure 1. Modeled household food security.

In the CC scenario, urban less educated households fell below the minimum caloric requirement (-17%) and were food insecure. Furthermore, Table 7 shows that the nutritional composition of this household category's consumption worsened, with greater dependency on grains and no change in the consumption of vegetables and fruits. This household category's consumption of nutrient rich and animal-based foods remained well below the desired intake with CC in 2030. Landless marginal, small farming, urban educated, large farmers, and nonagricultural rural households all surpassed the caloric minimum by 45%, 50%, 60%, 91%, and 224%, respectively. On the whole, CC reduced total household caloric consumption by 17%.

6. Discussion and Policy Implications

Economic growth, population dynamics, and changes in preferences towards more input-demanding, higher value crops are driving demand for agricultural commodities. Global food stocks have been on the decline, increasing the exposure of developing and developed countries to shortfalls due to climate variability, risk, and speculator behavior. CC will further exacerbate the challenges Bangladesh faces in meeting its growth and food security targets. Rising temperatures will increase crop evapotranspiration reducing crop yields while sea level rise will make cultivable land scarcer. To counteract these forces, some exogenous in nature, Bangladesh will have to make more effective use of increasingly scarce resources. In this paper, we developed a DCGE model linked to a food security module to explore the degree to which CC may impact the agricultural sector and the economy overall. In the face of CC, we used modeling results to shed light on the country's trajectory toward a more food secure future.

We found that CC imposed on the agricultural sector had a relatively small effect on GDP, reducing it by 29,925 million BDT in 2030 (-0.11%), or by 6313 million BDT in present value terms. For the agricultural sector, the CC impact resulted in contraction of some subsectors or slower growth in others, slower export growth and higher rates of growth in agricultural imports, particularly for rice. In 2030, agricultural sector output and exports were -1.23% and -0.28% lower, respectively with CC, while agricultural sector imports were 1.52% higher. Prices for most goods and services grew slower than in the baseline or contracted even further. Household income grew slower as a result of CC impacts.

Although the CC impacts simulated showed a relatively small effect on overall economic growth at least in the short run until 2030, results of our food security analysis reveal that CC will pose real challenges to achieving food security. In the absence of CC, all household categories became food secure by 2030. With CC, although the food security of urban less educated households improved, they remained food insecure. In addition, the nutritional composition of this household category's consumption worsened, with a greater dependency on grains and a less than desirable share of calories derived from fruit, vegetables, and animal-based foods. Overall, CC

reduced Bangladesh's total caloric consumption by 17% compared with the baseline projection.

The fact that there is considerable food insecurity in the initial years of the modeling exercise, improving with the prospect of enhanced growth, is of policy relevance. The trajectory towards food security differs both temporally and spatially, indicating the need for policies that can leverage the positive impact of growth and maximize the number of households that move towards a food secure future at the least cost. While data availability limited the possibility of a spatially disaggregated SAM, it is reasonable to expect that CC impacts will be felt more acutely in the most vulnerable regions such as coastal and drought prone areas. The spatial dynamics (rural/urban, coastal/inland, upland/lowland) of food security will require the development of targeted policies and programs.

Findings indicated that rice imports will grow faster as a result of CC. For years, Bangladesh's government has maintained a policy of national food self-sufficiency, using rice imports primarily as a mechanism for maintaining domestic price stability. Although the economic model developed here allows for endogenous growth of imports based on domestic to foreign price ratios, in reality this may not occur. From a political perspective, a policy of meeting food security targets through greater dependence on foreign markets is unlikely to be politically acceptable, given Bangladesh's experience with recurring famine (Banerjee *et al.*, 2014). The implications of this are that future caloric deficits may be greater than those estimated here. To compensate for this gap, domestic agricultural output would have to grow faster.

Crop yield impacts and sea level rise are only two potential CC impacts that were simulated in this analysis. Other consequences of CC may also have a significant impact on the economy and households, for example the potential health impacts and their implications for many aspects of development including labor productivity. Also not evaluated was the potential for a trend of increasing intensity and frequency of extreme weather events. These events could include cyclonic storms, severe flooding and severe drought. With sea level rise, saline intrusion is also a concern where saltwater pushes its way upstream, contaminating groundwater supplies and rendering once cultivable areas unmanageable. The inclusion of these and other potential CC impacts would exacerbate the economy-wide and household-level food security responses presented here.

Bangladesh has been adapting to climate variability and change for decades. Increasing waterlogged areas, for example, has prompted research into crop varieties tolerant of such conditions. With groundwater extraction for irrigation in some areas of the country's northwest beginning to show signs of stress, various policies and programs have been encouraging the agricultural development of coastal regions. Salt-tolerant crops and appropriate management strategies are being pursued to overcome the challenges characteristic of coastal regions. The development of higher yielding varieties and other technological innovations will also help meet growing demand.

Nonetheless, to keep pace, investment in research and development will be critical to continue to encourage this form of innovation.

This study demonstrated that although CC as modeled here, had a relatively small impact on overall growth in the short run until 2030, it does present challenges for achieving household-level food security. Overall, Bangladesh is likely to produce enough food to satisfy and even surpass its caloric requirements by 2030. Despite surplus production, however, some will still go hungry and undernourished. This phenomena relates to both inter- and intra-household distribution of food and nutrition. The results presented here show that underfed individuals persist in some household categories and the nutritional composition of their diets worsens. Improving food distribution is a key policy imperative if Bangladesh is to achieve its vision of offering its people a comparable standard of living to that of middle-income countries in the near term. Once considered a “test case of development”, with its advances in social welfare and economic growth in the last decade, Bangladesh has certainly demonstrated it is up for the challenge.

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