The economic influence of climate change on Bangladesh agriculture: application of a dynamic computable general equilibrium model

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Abstract

Purpose – Evaluating the economic effects of climate change is a pivotal step for planning adaptation in developing countries. For Bangladesh, global warming has put it among the most vulnerable countries in the world to climate change, with increasing temperatures and sea-level rise. Hence, the purpose of this paper is to examine how climate change impacts the economy in Bangladesh in the case of climate scenarios.

Design/methodology/approach – Using a dynamic computable general equilibrium (CGE) model and three climate change scenarios, this paper assesses the economy-wide implications of climate change on Bangladesh's economy and agriculture. It is clear from the examination of the CGE model that the impacts of climate change on agricultural sectors were felt more sharply, reducing output by −3.25% and −3.70%, respectively, and increasing imports by 1.22% and 1.53% in 2030 and 2050, compared to the baseline.

Findings – The findings reveal that, relative to baseline, agricultural output will decline by a range of −3.1% to −3.6% under the high climate scenario (higher temperatures and lower yields). A decrease in agricultural output results in declines in agricultural labor and household income. Household income falls in

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all categories, although it drops the most in urban less educated households with a range of −3.1% to −3.4%. On the other hand, consumption of commodities will fall by −0.11% to −0.13%, according to the findings. Although climate change impacts had a relatively small effect on gross domestic product, reducing it by −0.059% and −0.098% in 2030 and 2050, respectively.

Practical implications – As agricultural output, household consumption and income decline, it will impact the majority of the population's health in Bangladesh by increasing malnutrition, hidden hunger, poverty, changing food environment, changing physical and mental health status and a changing health-care environment. Therefore, population health and food security will be a top socioeconomic and political concern for Bangladesh Government.

Originality/value – The examination of the dynamic CGE model is its originality. In conclusion, the evidence generated here can provide important information to policymakers and guide government policies that contribute to national development and the achievement of food security targets. It is also necessary to put more emphasis on climate change issues and address potential risks in the following years.

Keywords Agriculture, Bangladesh, Climate change, Dynamic computable general equilibrium model, Food security

Paper type Research paper

1. Introduction

Bangladesh is a country in northeastern South Asia with a total area of 1,47,570 square kilometers (56,977 square miles) and often referred to as a riverine country, with one of the world's largest deltas, with a substantial portion of the delta lying below three meters above sea level. Bangladesh's population is expanding by 1.29% at an average annual growth rate and will reach 247 million by 2050 (Banerjee *et al.*, 2015). Bangladesh is the most vulnerable country to cyclones and the sixth most vulnerable country to floods, according to the United Nations Development Program. This country is primarily an agricultural country, with agricultural workers accounting for the majority of the workforce (Hossain *et al.*, 2020). Due to global climate change, Bangladesh agriculture is extremely susceptible. The agricultural sector, which provides important livelihood resources, is crucial in determining Bangladesh's poverty levels. Nearly half of Bangladeshis work in agriculture either directly or indirectly, and rice is the single-most-important producing an agricultural product. Agricultural sectors grew negatively due to climate change, and it is a significant concern for Bangladesh's development and food security (Banerjee *et al.*, 2015). Bangladesh has a subtropical monsoon climate; summer is hot and humid from March to May, followed by the monsoon season from June to September and a dry winter from November to February (Hossain *et al.*, 2021). During the monsoon season, up to 66% of the nation might be immersed, and cyclones and storm surges happen regularly. Floods linked with cyclones and other large coastal storms are projected to become more common and severe in the future as a result of global climate change and increased sea-level rise. Sea-level is increasing alarmingly in the southern part of Bangladesh. The southern part of Bangladesh is more vulnerable due to sea-level rise. Sea level rise has a huge socio-economic and environmental impact, and it is expected to cause macroeconomic shocks in Bangladesh in the long run. The negative effects of rising sea levels will limit the economy's growth potential. At the same time, rising sea levels will have a greater impact on coastal agricultural production (Uzzama, 2014). Another big challenge in Bangladesh's agriculture is rising temperatures. A study conducted by Hossain *et al.* (2020), found that the overall temperature tends to increase by 1°C, 1.6°C, 2°C and 2.4°C in the years 2030, 2050, 2070 and 2100, respectively. Precipitation is also projected to increase in 2030, 2050 and 2070. Climate change is already influencing population health, food, crop production, water security, ecosystems, infrastructure and other areas in Bangladesh, and climate-related dangers will become more severe in the future (Chandio *et al.*, 2021; Biswas *et al.*, 2021; Jabed *et al.*, 2020; Uddin *et al.*, 2017; Ebi *and Bowen*, 2016).

Bangladesh is particularly susceptible to climate extremes in the near future, in the form of extreme heat waves, which will have a significant impact on agricultural productivity (Choi *et al.*, 2021). Global climate change, for example, is expected to cut Bangladesh's gross domestic product (GDP) by 29,925m Bangladeshi Takas (−0.111%) by 2030, with agricultural output declining by 1.23% and food imports rising by 1.52% (Banerjee *et al.*, 2015). Other South Asian countries' prospects are not much better than Bangladesh's. Around 80% of overall losses are borne directly by household consumption, posing a serious threat to household welfare. Hence, the geological area and geomorphological conditions have made Bangladesh perhaps the most vulnerable to climate change. Bangladesh has two options: adaptation and mitigation. The first is country-specific, or even local-specific, whereas mitigation requires global communities to work together. Although Bangladesh is one of the least responsible countries for global climate change, the country's high sensitivity to its effects is clear, and adaptation is the only way to deal with the problem.

Therefore, the motivation behind this paper is to examine the potential impact of climate change in the long run. This paper considers climate change impacts on food production and households' ability to purchase food. The outcome of the dynamic computable general equilibrium (CGE) module has been analyzed to evaluate the climate change impact on various household categories. In this paper, a forecast baseline was constructed projecting Bangladesh's economy to the year 2050 in the absence of any climate shock. Three climate change scenarios were compared to this shock. Natural climatic changeability and climate change were placed on the model by the three scenarios. The main objective of this study is to compare forecast baseline scenarios in macroeconomic, sectoral and household-level indicators with policy scenarios that reflect the economic outlook in Bangladesh as a whole. The following are some of the study's other goals:

- examine the impact of climate change on agricultural production and household income;
- study the implications of climate change scenarios on total imports and exports; and
- investigate the effects of various climate change scenarios on consumption and food security.

Taking into account the foregoing, this research paper develops a dynamic CGE model to assess how climate change may affect agriculture and the economy of Bangladesh as a whole. There are few studies that analyze the impact of climate change in Bangladesh using the CGE model, and this research paper aims to address that gap, which will eventually assist policymakers and policy analysts make better decisions. Finally, this paper is coordinated as follows. Following this introduction, previous literature is explained in Section 2. The research techniques are introduced, providing an overview of the dynamic CGE approach in Section 3; a preliminary exploration of the core data source and the SAM explained in Section 4. The scenario analysis of climate change described in Sections 5 and the Section 6 presents the results of the CGE analysis. Section 7 provides a conclusion and the policy implications of the findings.

2. Previous study that used the computable general equilibrium model

CGE models are now a common technique for empirical analysis and are mostly used for agricultural market analysis globally. CGE models are increasingly becoming a popular tool to assess the possible economic implications of climate change, as witnessed by the surge in similar research around the world (Pradhan and Ghosh, 2019; Fujimori *et al.*, 2016; Böhringer *et al.*, 2021; Bezabih *et al.*, 2011; Mideksa, 2010; Hertel *et al.*, 2010; Arndt *et al.*, 2011; Iglesias *et al.*, 2012; Ochuodho *et al.*, 2012; Aaheim *et al.*, 2012). Because of its economy-wide and market-based approach, the CGE modeling approach is considered a suitable tool for such studies (Iglesias *et al.*, 2012).

Various models have been used in many studies throughout the world to examine the effects of climate change on agriculture and possible adaptation measures. Previous studies have examined the economic ramifications of climate change impacts using CGE models (Solomon *et al.*, 2021; Bosello *et al.*, 2007). Only a few studies consider the effects of climate change on agriculture on the entire economy. For measuring the economic effects of climate change and evaluating the efficacy of climate policy, top-down CGE modeling is commonly used in various studies (Robinson *et al.*, 2014; Bandara and Cai, 2014; Bezabih *et al.*, 2011). According to these studies, unfavorable climatic change in some developing nations is projected to cause not only income and consumption disparities but also a significant drop in their overall economic performance.

Thurlow *et al.* (2009), used a hydro-crop model with a dynamic CGE (DCGE) model, the result estimated climate variability in Zambia is projected to cost US$4.3bn over 10 years, with a worst-case rainfall scenario costing as much as US$7.1bn. Robinson *et al.* (2012), used the dynamic CGE model of Ethiopia with a system of country-specific hydrology, crop, road and hydropower engineering models to examine the impact of climate change on GDP, consumption and income. They found that by 2050, GDP will be 10% lower than the no-climate-change baseline, with climate change impacts disproportionately affecting the poor. Another study conducted by Vatankhah *et al.* (2020), find that improving the climate will increase the country's economic potential and reduce costs, while adverse climate conditions will worsen the country's economic situation and, consequently, increase costs. Economic studies of climate change have shown that although global warming may improve global productivity in the short term, it will have a detrimental influence on production in the long run (Vista, 2014; Reidsma *et al.*, 2009).

Climate change harms a variety of factors, including economic growth (Kalkuhl and Wenz, 2020; Diffenbaugh and Burke, 2019), human well-being (Hsiang *et al.*, 2013), energy demand (Wenz *et al.*, 2017) and ecosystems (Hoegh-Guldberg and Bruno, 2010). Agriculture is the most sensitive sector to climate change and ecological degradation, as environmental conditions are the key determinants of agricultural productivity. Furthermore, the rural population, particularly in low-income countries, will be negatively affected by climate change due to less adaptation ability (Coulibaly *et al.*, 2020; Aryal *et al.*, 2020); poor infrastructure, limited financial resources and low productivity. Changes in climatic conditions have been claimed to have exacerbated the severity of food insecurity in many food-insecure countries, as well as a drop in consumable calories in many countries (Almazroui *et al.*, 2020; Ray *et al.*, 2019). Therefore, an understanding of the magnitude and speed of climate change, as well as its effects on agriculture at the regional level, is required, as are timely and suitable government policies on climate change (Vatankhah *et al.*, 2020).

3. Computable general equilibrium model used in this paper

The CGE model has been used to analyze the economic impact of countries/regions. The CGE model is one of the popular numerical simulation tools used to assess the effects of economic shocks and is particularly useful for analyzing the impact of policy changes. The module used in this paper is a dynamic model. This model was built primarily to accurately portray a country's economic environment. The rest of this section goes through the details of the dynamic CGE model.

3.1 Overview of the computable general equilibrium model

CGE models are a type of economic model that uses real-world data to predict how an economy will react to policy, technology and other external influences (Burfisher, 2021). In 1960, Johansen established a multi-sectoral growth model to study economic growth in Norway, which meant the beginning of the CGE model. Since then, almost all the developed countries and most of the developing countries have established their CGE models. CGE models are widely used in analyzing the impacts of economic shocks whose effects may be transmitted through multiple markets. The CGE model can represent the economic performance of countries and regions (Hossain and Delin, 2022). A CGE model can capture all economic linkages through a price mechanism (Hosoe, 2014). The CGE model specifies all economic relationships in mathematical terms and puts them together in a form that allows the model to predict the change in variables such as prices, output and economic welfare. The core principle of any CGE model is the circular flow of commodities (Hosoe, 2014). Households and firms are the main actors in the circular flow. In many CGE models, the government is also explicitly represented in the circular flow, collecting taxes and disbursing these revenues to firms and households. The model's equilibrium condition is maintained via circular flows. Additionally, market clearing conditions are the key feature of the CGE model that depicts supply should equal demand in every market-goods, factors, foreign exchange and everything else (Hossain and Delin, 2022).

3.2 The dynamic computable general equilibrium model in this paper

The model constructed here is based on the International Food Policy Research Institute's (IFPRI) standard CGE model and Thurlow's dynamic extension to the model. General Algebraic Modeling System is used for the implementation of the model and the solving method is the mixed complementary problem using the PATH solver (Lofgren *et al.*, 2002). IFPRI developed this model to facilitate the use of CGE models in developing countries. The model is dynamic and provides additional insight, portraying the transition path of an economy considering labor migration, wages, investment behavior, policy or environmental shocks (Thurlow, 2004). Furthermore, the dynamic framework in the model enables the dynamic effects of direct, indirect and induced benefits to be captured. The dynamic model enables the updating of factor stocks in both baseline and policy shock scenarios. The model makes labor assumptions that are appropriate for the particular region being modeled. While labor supply is updated based on the estimated labor force growth rate, capital stocks are updated endogenously based on the previous period's allocation of investment and the rate of capital depreciation. The dynamic model follows a balanced macroeconomic environment where investment and government consumption shares are fixed while the quantities are flexible. At base year levels, nominal absorption shares of investment and government consumption are fixed. The factors labor, capital and agricultural land are fully employed and mobile among sectors in the baseline and policy scenarios. Although the structure and mathematical description of the dynamic CGE model are documented in Thurlow (2004) and Lofgren *et al.* (2002) in detail, the basic structure of the model is presented here.

In the model, producers always aim to maximize profits while being constrained by nested technological restrictions. In the technology nest, domestic and imported commodities are combined into a composite intermediate input based on fixed shares. The constant elasticity of substitution (CES) aggregation primary factor input generates value-added in the model (Annabi *et al.*, 2006). Until the primary factors are used, the marginal revenue product for each factor is equal to its price. Depending on the factor market closure, the value paid to a specific factor can vary by area. Intermediate and value-added inputs are aggregated according to Leontief fixed shares. Any actor in the economy can produce more than one commodity at the activity level, where a particular sector's commodities are determined by fixed yield coefficients.

The component by which the supply of a factor equilibrates with demand is depicted by factor market closures in the model. The model takes into account three main factors in market closures, the decision of which relies upon the application and the temporal scale under consideration. The first closure fixes the quantity of a factor at the benchmark level, and the factor is fully used and mobile between sectors. The Keynesian closure is the second type of closure, in which the economy-wide factor wage is fixed, and the factor may be underemployed. The third closure is a segmented market closure, in which each industry employs the base-year amounts of a factor. In this closure, economy-wide wages and factor demands are fixed and industry-specific wage and supply are flexible. This closure is often used for short-term analysis.

The institutions in the model are different household income classes, a general enterprise, an interest account, a government and the rest of the world. Households purchase marketed commodities according to a linear expenditure system (LES) where households use their income to consume a minimum level of subsistence goods and services at the very first. According to a linear relationship between income and consumption, any money left over after subsistence consumption is spent on goods. The contrast between the CES function and the LES function is that income elasticity in the LES function is non-unitary (Annabi *et al.*, 2006; Decaluwé *et al.*, 2010). All households pay direct taxes (income and property taxes); mid and high-income households additionally save. Labor and capital provide income to all households, whereas agricultural returns provide income to middle- and high-income households. In addition, households receive transfers from the government, the enterprise and the rest of the world, including social security benefits, interest as property income and the enterprise. The fixed shares of household income are considered direct taxes and transfers to domestic institutions. The savings of households are both flexible and specified. The enterprise pays direct taxes, pays interest as property income, saves and transfers factor income to households. The enterprise receives income from capital and agriculture. The distinction between the enterprise and the behavior of households is that the enterprise does not consume. Direct tax payments and transfers are fixed shares of enterprise income on account of households, whereas savings are flexible. The interest account receives income from the enterprise, the government and the rest of the world and transfers its entire income to households. The government receives income from the direct, indirect and commodity tax accounts as well as the tariff account. Public goods and services produced by the public administration sector are consumed by the government, while less consumption is in private services. The government pays property interest and saves. In addition, the government makes transfer payments to households which are indexed by the consumer price index (CPI). Government savings may be negative and are treated as flexible residuals. The rest of the world makes transfers to households and receives (when the column entry is negative) income from interest and purchases exports. The current account deficit (where the column entry is negative) is the difference between a country's expenditure and receipts, and it represents the rest of the world's savings. The rest of the world receives payments from the sale of imported goods.

In the model, specific commodity outputs from various sectors are treated as imperfect substitutes due to differences in output quantity, timing and market distance. Thus, commodity prices are sector-specific. The demand for a sector's output is determined by minimizing the cost of supplying the aggregate commodity subject to the CES function. Aggregate domestic output is subject to a constant elasticity of transformation function. At fixed world prices, export demand is infinitely adjustable. Domestic consumer demand is composed of imports and domestic output. Armington's assumption is utilized to determine domestic demand where consumers minimize costs subject to imperfect substitutability between domestically produced and imported goods. International supplies of goods are elastic at fixed prices. The Armington assumption assures clearance of the domestic market by allowing some flexibility between domestic and world prices.

The model maintains three macroeconomic balances: the government current account balance; the current account of the balance of payments and the savings and investment balance. These balances are known as closure rules, which are needed to maintain a balanced economic environment. Concerning the government account, tax rates may be fixed with government savings calculated as a flexible residual. Alternatively, direct tax rates are flexible and savings for the government might be fixed. The current account of the balance of payments may be maintained by a flexible real exchange rate and fixed foreign savings. Alternatively, the real exchange rate may be fixed, allowing for a flexible current account deficit and trade balance. For the savings and investment balance, there are three main types of closures: a balanced closure; the Johansen closure and a neoclassical closure. Balanced closure and Johansen closure are investment-driven, and neoclassical closure is savings-driven. Lofgren *et al.* (2002) give more details about the closure. The model behaviors have a significant relationship to the choice of closure rules (Ezaki, 2006; Holland, 2010). The closure rule adopted in balanced closure is sensitive to the sectoral distribution. The model policy shocks are chosen by some macroeconomic closure settings and give the potential sensitivity of model behavior to the closure rules.

The economic model of this paper has different limitations and uncertainties. Some of these uncertainties are future projections of climate change and its effects. One type of uncertainty arises from the fact that we do not yet know how human activity will affect the climate in the future. For instance, factors such as population growth, economic expansion, technological advancement, energy demand and supply techniques, and land use all have an impact on future greenhouse gas emissions. The main limitation of the economic model in this paper is uncertainty about the accuracy of the underlying data and the values of behavioral parameters. The CGE model, for example, is calibrated to the social accounting matrix (SAM), which captures current production technologies and linkages. The CGE model can forecast some endogenous change from existing technologies, but it cannot predict the formation of wholly new technologies or economic sectors. Although the CGE model in this paper is based on the best available data on Bangladesh's economic structure and institutional behavior, both of these characteristics could change significantly during the long periods simulated in this study.

4. Model aggregation and databases

The SAM is the core data source for the DCGE model. SAM describes the payments and receipts between economic agents, factors and intermediate and final commodities and services in an economy. SAM is an accounting table that records the flows of an economy in a specific period and maintains a row and column that records the payment from the column account to the row account. Thus, the income flow of an account appears in a row and expenditure appears in a column. The CGE model explains all the payments in the model by following the factors, activities, commodities and institutions contained in SAM. The SAM used in this paper is based on Bangladesh's SAM for 2006/2007. The base year of 2006/2007 was chosen because all comprehensive data on Bangladesh's economy was available this year. On the other hand, the global economic crisis and other shocks such as extreme weather events had no impact on Bangladesh's economy this year. The procedure for building the SAM is documented in detail in Khondker and Raihan (2011).

The SAM is used in this paper to focus on the agriculture sector in Bangladesh. The economy is aggregated into 20 sectors/commodities, with agriculture and food production accounting for 12 of them (Table 1). Land, skilled and unskilled labor, capital and factors of production are all included in the SAM. The SAM consists of 11 institutions, 8 of which are households, with 6 rural and 2 urban.

The Household Income and Expenditure Survey classification system is used to categorize households in SAM. The characteristics of the households in the model are detailed in Table 2. Agricultural households in rural areas are classified according to their land holdings, whereas nonagricultural households are classified according to whether or not they are poor.

The two urban household types are dis-aggregated by level of education. Urban less educated households possess less than or equal to 8th class education, and urban higher educated households possess greater than 8th class education (Table 2). Finally, the remaining three institutions are the government, firms and the rest of the world. The final two accounts in the SAM include public and private investment and inventories.

5. Model simulation scenarios

The current study measured the impact of climate change on Bangladesh's agriculture sector. For this purpose, the crop model (DNDC) was used to estimate the function of agricultural sector production that is impacted by climate (temperature and precipitation),

Table 1. Aggregation in the model

Agricultural sectors	Non-agricultural sectors
Rice	Forestry
Wheat	Public administration
Other grains	Manufactured goods
Potato	Construction
Vegetables	Mining and gas
Pulses	Trade
Other crops	Transport
Fruit	Services
Livestock	
Poultry	
Fish	
Processed food	

Table 2. Household categories in the model

Household type	
Landless (0 ha)	Rural poor nonagricultural
Marginal (≤ 0.198 ha)	Rural non-poor nonagricultural
Small agricultural (0.202 to 1.008 ha)	Urban educated
Large agricultural (agricultural > 1.012)	Urban less educated

Source: Banerjee *et al.* (2015)

and the effect of climate change on the agricultural sector was analyzed in the CGE model framework. In this investigation, various scenarios were used.

5.1 Baseline forecast

Bangladesh's economy was projected using the baseline scenario from the base year of 2006/2007 to 2050. This scenario assumes the historical tendencies of Bangladesh's economy without climate change. The overall economy, including productivity, yields and factors of production, followed a balanced growth path in the forecast in this scenario. At this baseline, total factor of production growth was estimated at 1% for all sectors of the economy. The average growth rate of the population and labor force was estimated at 1.29% at baseline.

5.2 Climate change scenarios design

The climate change scenario simulated projected climate change impacts and estimated by future climate scenarios. The estimation for future temperature and precipitation changes has been taken from IPCC (Intergovernmental Panel on Climate Change climate) model such as coupled Model Intercomparison Project Phase 5 (CMIP5) results under the Representative Concentration Pathway (RCP) emission scenarios. In this study, the average result of 16 CMIP5 coupled models (e.g. BCC-CSM1-1, BCC-CSM1-1-m, CCSM4, CESM1-CAM5, CSIRO-MK3-6–0, FIO-ESM, GFDL-CM3, GFDL-ESM2G, GISS-E2-H, GISS-E2-R, HadGEM2-AO, HadGEM2-ES, MIROC5, MIROC-ESM, MIROC-ESM-CHEM and NorESM1-M) have been taken consideration for the projection of climate scenario in Bangladesh. Various climate models are used in projections to avoid uncertainty because one specific model may increase the uncertainty of the result. The average results of the 16 climate models indicate that temperatures will increase by 1°C and 2°C in the years 2030 and 2050, respectively. Precipitation trends in 2050 were not possible to estimate more accurately with regard to 2030. The results from the literature have been taken into consideration also for the estimation of precipitation in 2050. Sea-level rise has not been taken into consideration in this paper because this study assumes that there will be no notable changes in sea level until 2050. If the paper extended to 2100, then sea-level rise might be taken into consideration. The dynamic model of this paper was run from the base year to 2050. For each of those years, a random historical climate observation was drawn. Based on random observation, crop yield impacts were estimated by the crop modeling framework.

In the climate change scenario, shocks were imposed in each of the three climate scenarios. Scenario 1 is the low impact climate scenario, where population and labor force growth is estimated to increase by 1.3% and crop yield is estimated to decrease by −10%. Scenario 2 is the medium climate scenario, where population and labor force growth is estimated to increase by 1.7% and crop yield is estimated to decrease by −20%. Scenario 3 is the high impact climate scenario, where population and labor force growth is estimated to increase by 1.8% and crop yield is estimated to decrease by −30%.

6. Results and discussion

The findings of this study address the influence of climate change on agricultural output and the economy in Bangladesh in the years 2030 and 2050, but not beyond 2100 due to data limitations. The contrast between the baseline without a climate shock and the policy scenario with a climate shock is examined in this section. Table 3 shows how macroeconomic indicators would be affected by climate change in 2030 and 2050. The difference between climate change scenarios and the baseline scenario is provided by the outcome. It can be seen from the table that climate change impacts on all macroeconomic indicators. The negative deviation in 2030 from the baseline increases in private consumption from −0.031% to −0.046% and GDP from −0.017% to −0.022% when low to high climate change scenarios are taken into account. Where exports and imports grew faster than the baseline in all climate change scenarios in the year 2030. On the other hand, introducing the climate shock in 2050, GDP grew slower by −0.029% and −0.037% in medium and high climate change scenarios, whereas GDP in low climate change scenarios grew slower by −0.024%. Private consumption decreases from −0.039% to −0.067% in all scenarios. In contrast, exports, imports and fixed investments raised a short amount in all climate change scenarios in the year 2050 compared to baseline.

Table 4 highlights the effect of climate change on overall household income in 2030 and 2050. With climate change scenarios, there are some dissimilarities of household income observed among different household groups. While, for small farmers (from −0.188% to −0.308%), urban less educated (from −0.187% to −0.314%), and rural non-poor non-agricultural (from −0.189% to −0.305%) households, income growth slowed more in 2030. In addition, household income for urban less educated and small farmer households stays much lower in 2050 compared to 2030. In 2050, household income falls −0.335% and −0.281% for small farmers in the high and medium climate change scenarios, respectively, and falls −0.342% and −0.285% for urban less educated households. One exception is rural poor non-agricultural and urban less educated households, where income falls rapidly compared to other households. In regard to all climate change scenarios, household income grew slower, which has a negative influence on all household categories. Hence, all household types were found to be equally vulnerable to climate shocks compared to baseline in 2030 and 2050, respectively.

Table 3. Changes in macro indicators from baseline (% change)

	2030			2050		
Macro Indicators	CC low	CC medium	CC high	CC low	CC medium	CC high
Private Consumption	−0.031	−0.04	−0.046	−0.039	−0.058	−0.067
Fixed Investment	0.003	0.008	0.011	0.005	0.012	0.015
Exports	0.033	0.053	0.061	0.045	0.078	0.086
Imports	0.032	0.052	0.061	0.039	0.078	0.098
GDP	−0.017	−0.02	−0.022	−0.024	−0.029	−0.037

Note: CC = Climate change
Source: Dynamic CGE model result

Table 4. Difference in household income from baseline (% change)

	2030			2050		
Households	CC low	CC medium	CC high	CC low	CC medium	CC high
Landless	−0.184	−0.262	−0.305	−0.19	−0.277	−0.332
Marginal	−0.188	−0.264	−0.307	−0.194	−0.28	−0.334
Small farmers	−0.188	−0.265	−0.308	−0.194	−0.281	−0.335
Large farmers	−0.189	−0.264	−0.307	−0.195	−0.28	−0.334
Rural poor non agricultural	−0.188	−0.265	−0.309	−0.194	−0.281	−0.336
Rural non poor non agricultural	−0.189	−0.263	−0.305	−0.195	−0.278	−0.332
Urban less educated	−0.187	−0.269	−0.314	−0.193	−0.285	−0.342
Urban educated	−0.188	−0.262	−0.305	−0.194	−0.277	−0.332

Note: CC = Climate change
Source: Dynamic CGE model result

Table 5 depicts household consumption in different categories. The combined effects of changes in real income and variations in food prices affect agricultural output used for household consumption. From an economy-wide perspective, the unfavorable effects of climate change on consumption are disproportionately felt by rural poor non-agricultural and urban less educated households. In rural poor non-agricultural households, consumption of potatoes, vegetables, pulses, other crops and grain decreases by −2.03%, −2.15%, −3.07%, −1.07% and −1.19%, and in urban less educated households, consumption decreases by −1.94%, −2.06%, −2.99%, −1.43% and −1.10%. Other households' consumption of agricultural products declined as well as compared to baseline. When compared to baseline scenarios, climate change has had a bigger impact on rice consumption, which has declined by −19.47% to −21.14%, and livestock consumption, which has decreased by −12.03% to −12.69% in all household categories. Hence, these repercussions will very likely have an impact on the population's overall health.

Table 6 outlines the combined impact of high climate shocks on exports, imports, and domestic output in the years 2030 and 2050. In 2030, domestic agricultural output will decrease by −0.132% for wheat, −0.149% for other grains, −0.086% for potatoes, −0.061% for vegetables, −0.048% for pulses and −0.059% for fruits. The impact of climate change decreased livestock production by −0.176% and rice growth by −1.028%, while other commodity output shrank even more. Most commodities saw increased imports, with the exception of wheat, other grains, potatoes, vegetables, pulses, and fish, which saw decreased imports. As a result, imports of rice increased by 0.818%; livestock increased by 0.393%; fruit increased by 0.012%, and other crops increased by 0.022%. In 2030, total agricultural imports will increase by 1.22%, where import of agricultural food items in Bangladesh is 9% of the total imports in 2022. Furthermore, climate change reduces the exports of rice, wheat, potatoes, vegetables, pulses, fruit, other crops, livestock and poultry. Overall agricultural export contracted further by −2.818%. Consecutively, in the year 2050, most agricultural imports grew more slowly, with the exception of rice, which grew at a quicker rate of 1.022%. Exports of agricultural products increased much more slowly than anticipated, especially those of rice, which decreased by −1.429%. Except for forestry, which saw a growth of 0.004%, other divisions of domestic agriculture sub-sectors

Commodity	LANDLESS	MARG	SMALL	LARGE	RPNA	RNPNA	URBNEDU	URBEDU
Potato	−1.68	−1.75	−1.80	−1.81	−2.03	−1.43	−1.94	−1.28
Vegetables	−1.82	−1.88	−1.93	−1.95	−2.15	−1.59	−2.06	−1.43
Pulses	−2.67	−2.69	−2.76	−2.76	−3.07	−2.30	−2.99	−2.23
Fruit	−2.50	−2.51	−2.58	−2.58	−2.92	−2.10	−2.84	−2.03
Other crops	−1.23	−1.31	−1.35	−1.37	−1.52	−1.07	−1.43	−0.88
Livestock	−12.38	−12.36	−12.42	−12.41	−12.69	−12.01	−12.64	−12.03
Poultry	−3.55	−3.62	−3.66	−3.68	−3.84	−3.36	−3.76	−3.21
Fish	−1.08	−1.17	−1.21	−1.23	−1.37	−0.93	−1.28	−0.74
Forestry	−0.62	−0.71	−0.75	−0.77	−0.90	−0.48	−0.82	−0.29
Rice	−20.60	−20.27	−20.41	−20.29	−21.06	−19.47	−21.14	−20.13
Grain	−0.90	−0.99	−1.03	−1.05	−1.19	−0.76	−1.10	−0.57
Processed food	−2.05	−2.13	−2.17	−2.20	−2.33	−1.89	−2.25	−1.72

Notes: LANDLESS = Landless; MARG = Marginal; SMALL = Small agricultural; LARGE = Large agricultural; RPNA = Rural poor nonagricultural; RNPNA = Rural non-poor nonagricultural; URBNEDU = Urban educated; URBED = Urban less educated
Source: Dynamic CGE model result

Table 5. Changes in consumption by different households sector wise (% change)

Commodity	2030 Imports	2030 Exports	2030 Domestic output	2050 Imports	2050 Exports	2050 Domestic output
Rice	0.818	−1.265	−1.028	1.022	−1.429	−1.182
Wheat	−0.025	−0.167	−0.132	−0.032	−0.189	−0.152
Other grains	−0.036	−0.188	−0.149	−0.045	−0.212	−0.172
Potato	−0.002	−0.121	−0.086	−0.003	−0.137	−0.099
Vegetables	−0.01	−0.099	−0.061	−0.013	−0.112	−0.07
Pulses	−0.009	−0.088	−0.048	−0.012	−0.1	−0.055
Fruit	0.012	−0.107	−0.059	0.014	−0.121	−0.067
Other crops	0.022	−0.072	−0.046	0.027	−0.081	−0.053
Livestock	0.393	−0.49	−0.176	0.492	−0.554	−0.203
Poultry	0.092	−0.093	−0.029	0.115	−0.105	−0.033
Fish	−0.03	−0.017	−0.02	−0.037	−0.02	−0.023
Forestry	0	0	0.004	0	0	0.004
Processed food	−0.002	−0.109	−0.044	−0.003	−0.124	−0.051

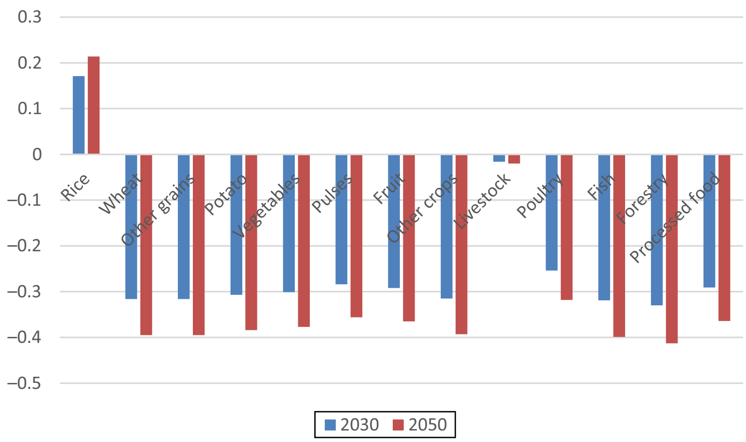
Source: Dynamic CGE model result

Table 6.
Sector-wise high climate change impact from baseline (% change)

progressed more slowly. The output of rice fell by −1.182% while the output of non-agricultural sectors increased at a faster rate.

Figure 1 depicts the variations in the commodity's composite price. In terms of agricultural composite prices, the climate shock further depresses the price for wheat by −0.316% and −0.395%, potato price by −0.307% and −0.384%, vegetables price by −0.301% and −0.377%, pulses price by −0.284% and −0.356%, livestock price by −0.016% and −0.02%, and fruit price by −0.292% and −0.365% in the year 2030 and 2050. Climate change had a negative impact on all prices except rice, which grew faster by 0.171% and 0.214% in 2030 and 2050 as a result of climate change.

Table 7 shows how labor supply has changed over time. The labor force was likewise separated into two types of labor: skilled and unskilled. When compared to other agricultural sectors, the rice sector has a much lower labor supply. In 2050, the rice sectors unskilled labor supply falls by −24.31%, while skilled labor supply falls by −24.66%. The



Source: Dynamic CGE model result

Figure 1.
Changes in composite price from the baseline (% change)

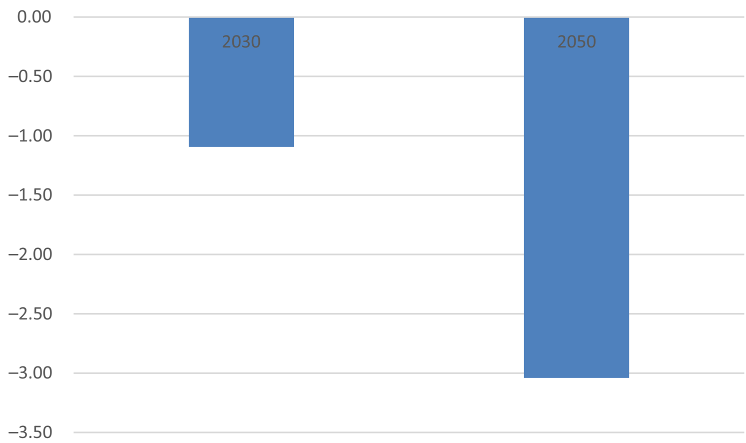
Commodity	Unskilled labor 2030	Unskilled labor 2050	Skilled labor 2030	Skilled labor 2050
Wheat	−16.41	−4.45	−16.35	−4.54
Potato	−6.46	−2.81	−6.39	−2.90
Vegetables	−5.02	−1.97	−4.95	−2.06
Pulses	−3.12	−1.47	−3.05	−1.57
Fruit	−4.84	−1.73	−4.77	−1.83
Other crops	−7.16	−1.12	−7.09	−1.22
Livestock	−6.58	−7.76	−6.52	−7.84
Poultry	−1.14	−1.28	−1.07	−1.38
Fish	−0.50	−0.86	−0.43	−0.95
Forestry	0.44	0.18	0.51	0.10
Rice	−19.72	−24.31	−19.45	−24.66
Grain	−0.73	−0.54	−0.39	−0.98
Processed food	−1.54	−1.70	−1.21	−2.14

Source: Dynamic CGE model result

Table 7. Changes in labor supply from the baseline (% change)

wheat sector follows the same trend as rice, where labor supply, both unskilled and skilled, decreases by −16.41% and −16.35% in 2030. Labor supply of both unskilled and skilled categories in 2050 increased in the wheat sector compared to 2030. Meanwhile, compared to baseline in 2030, the labor supply of potatoes, vegetables, fruits, and other crops in both categories appears to be good in 2050. In 2030 and 2050; however, the forestry sector's labor supply increased by 0.44% and 0.18% in the unskilled category, respectively, and 0.51% and 0.1% in the skilled category. It is clear from the table that the labor supply of all agricultural sectors drop between 2030 and 2050, with the rice, wheat, potato and livestock sectors being the lowest among them. The analysis shows that as a result of climate change, the labor force in the rice, wheat, potato, and livestock sectors will shift to other sectors such as manufacturing or service.

The variations in the CPI between 2030 and 2050 are depicted in Figure 2. In comparison to the baseline, the CPI declines by −1.09% in 2030 and −3.04% in 2050, as seen Figure 2.



Source: Dynamic CGE model result

Figure 2. Changes in consumer price index

The drop in CPI indicates a steady reduction in the prices of goods and services in Bangladesh.

This paper's findings are consistent with other studies (Solomon *et al.*, 2021; Banerjee *et al.*, 2015; Vatankhah *et al.*, 2020; Fujimori *et al.*, 2018; Ochuodho *et al.*, 2012) that show climate change has a negative influence on GDP, output, household income and consumption. The analysis of this paper also finds that climate changes will negatively impact agricultural production which is similar to previous studies (Tai *et al.*, 2014; Bandara and Cai, 2014; Sarker *et al.*, 2012). It is noticeable from the foregoing research that climate change has a negative influence on overall agricultural sectors in terms of export and production both in the years 2030 and 2050.

7. Conclusion and policy implication

In this research, a dynamic CGE model was created to investigate the influence of climate change on agricultural sectors and Bangladesh's economy as a whole. The differences in macroeconomic indicators, output, price and income between the baseline forecast and the climate change scenario reflect the effect of climate change on Bangladesh's economy. A baseline forecast which projected the economy to 2050 was established with three climate change scenarios low, medium and high, being considered. The baseline economy is steady without any climate shock and GDP growth was projected at 7.4%. When moving from low to high climate change scenarios, both private consumption, and GDP showed a negative deviation. Average GDP falls by −0.02% in 2030 and −0.03% in 2050, whereas average private consumption falls by −0.039% and −0.055% in 2030 and 2050, respectively. Despite this, exports, imports and fixed investment increased slightly compared to the baseline scenario. Climate change has the potential to have a substantial impact on Bangladesh's entire economy, as evidenced by the analysis of the results.

Climate change's growing influence has harmed all types of households. With medium and high climate change scenarios, urban less educated households and rural poor non-agricultural households had much more negative impacts. However, the impact of climate change on agricultural sectors has a minor influence on GDP, according to this study. In the agriculture sector, export and domestic output fell by −2.818% and −1.875%, respectively, in 2030, while overall imports rose by 1.22%, with rice imports remaining higher. In 2050, however, climate change scenarios reduced agricultural output and exports by −2.156% and −3.184%, respectively. Most commodities composite prices decrease at a slower rate, while rice prices increase by 0.332% and 0.416% in 2030 and 2050, respectively.

Even though climate change seems to have a minor impact on Bangladesh's total economic growth, the study finds that climate change will represent a serious threat to food security in the long run. In both 2030 and 2050, without a climate change scenario, all households become food secure; however, with a climate change scenario, the majority of households remain food insecure. In Bangladesh, rice is the most common food. According to the findings of this study, rice imports will increase by 0.818% and 1.022%, respectively, while rice prices will rise by 0.171% and 0.214% in 2030 and 2050 as a result of climate change. In Bangladesh, rice is consumed nearly three times a day by the majority of the population. As a result, any shifts in the production and price of rice will pose crucial challenges to Bangladesh's economy.

The result also shows household consumption of different categories decreases due to climate change impact. The decreases in different household consumptions will certainly have consequences on the general health of the population. This will further disrupt livelihoods, evict families from their homes, and push people into poverty. As a developing country, Bangladesh should place a higher emphasis on effective climate change adaptation techniques to ensure food security. Agricultural adaptations such as improved crop types, new cropping techniques, increased agricultural sector investment, infrastructure development, cropping pattern changes and other factors are among the most important because they will increase agricultural output, household consumption, household income and, ultimately, GDP in Bangladesh. Furthermore, numerous adaptation methods must be explored so that individuals can lessen the negative consequences of climate change on their health and well-being while also changing their habits to the new environment. Finally, several other climate change factors that were not taken into account in this study, such as urbanization, infrastructure development, external migration and remittances, population age structure and health and exogenous economic shocks, such as agricultural commodity price shocks, could have a significant impact. These are the study's limitations. As a result, future studies can take into account other aspects of climate change.

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