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CLIMATE CHANGE AND ECONOMIC GROWTH: EVIDENCE FROM BANGLADESH

Abstract

Bangladesh is widely recognised as one of the most climate-vulnerable countries in the world. Every year the country is exposed to a number of slow and rapid onset disasters that emanate from climate change. Even though some sporadic studies try to estimate the various economic effects of climatic events in Bangladesh, there is a lack of econometric analysis on the linkage between climatic variables and economic growth using its long-term time series data. Given this context, the paper tries to examine the effects of climate change on economic growth of the country using Autoregressive Distributed Lag model for the period 1981-2015. The empirical results reveal that lagged effects of greenhouse gas emission, increased temperature and rainfall have negative with statistically significant effects on the economic growth of Bangladesh.

1. Introduction

It is now unequivocally established that climate change is a reality, and the adversities of climate transformations pose as one of the greatest challenges to the contemporary world.[1] The Intergovernmental Panel on Climate Change (IPCC) defines climate change as "a change in the state of the climate that can be identified (*e.g.,* using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer."[2] Bangladesh experiences different climate-induced slow and rapid onset disasters, such as cyclones, recurring and extended floods, erratic rainfall, extended droughts, and salinity intrusion due to the sea-level rise (SLR). Thus, climate change is a significant threat to the lives and livelihoods of low-income people in the country. According to the Global Climate Risk Index 2016, annual average loss from disasters for 1995 to 2014 is 0.86 per cent of Gross Domestic Product (GDP) of the country.[3] Bangladesh has just graduated from the status of low-income to lower middle-income country, as classified by the

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[1] IUCN Bangladesh, *Protocol for Monitoring of Impacts of Climate Change and Climate Variability in Bangladesh*, Dhaka: International Union for Conservation of Nature, 2011, pp. xiv-182.
[2] IPCC, "Summary for Policymakers", in S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K. B. Averyt, M. Tignor and H. L. Miller (eds.), *Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report the Intergovernmental Panel on Climate Change*, Cambridge, United Kingdom and New York, USA: Cambridge University Press, 2007.
[3] S. Kreft, D. Eckstein and I. Melchior, *Global Climate Risk Index 2016*, Bonn: Germanwatch, 2015.

World Bank. There have been many other notable progresses in economic and social spheres during this short period including a trend of steady and impressive growth over the past ten years or so. However, climate change would come out with negative consequences for growth performances of the country.

A number of studies have been conducted so far on trends of change in climatic parameters in the context of Bangladesh. Warrick *et al*.[4], Karmakar and Shrestha[5] and Debsarma[6] provided assessment of changes in temperature and precipitation over Bangladesh, while Chowdhury and Debsarma[7] and Mia[8] reported assessment of the changes in temperature based on analysis of historical data of some selected weather stations in Bangladesh. Karmakar and Nessa[9] and Karmakar[10] provided assessment of the effects of climate change on natural disasters.

Haque *et al*.[11] indicated that the average increase in temperature would be 1.3°C and 2.6°C for the projected years of 2030 and 2075, respectively. In line with the IPCC projections, the rise in winter temperature in Bangladesh was predicted to be higher probably due to significant increase in monsoon precipitation, which could also cause severe flooding in the future. Chowdhury and Debsarma[12] studied that the projected changes would be 1.4°C in the winter and 0.7°C in the monsoon months in 2030. For 2075, the variation would be 2.1°C and 1.7°C for winter and monsoon, respectively. It has also observed the increasing tendency of lowest minimum temperature over Bangladesh. Warrick *et al*.[13] studied the variation of temperature and rainfall over Bangladesh. In their study, mean-annual temperatures have been expressed as departures from the reference period 1951-1980. It is evident that during

[4] R. A. Warrick, A. H. Bhuiya and M. Q. Mirza, *The Greenhouse Effect and Climate Change: Briefing Document*, No. 1, Dhaka: Bangladesh Unnayan Parishad, 1994.
[5] S. Karmakar and M. L. Shrestha, "Recent Climate Change in Bangladesh"*, SMRC Series*, No. 4, Dhaka: SAARC Meteorological Research Centre, 2000.
[6] S. K. Debsarma, "Intra-annual and inter-annual variation of rainfall over different regions of Bangladesh", *Proceedings of SAARC Seminar on Climate Variability in the South Asian Region and its Impacts*, Dhaka: SAARC Meteorological Research Centre, 2003.
[7] M. H. K. Chowdhury and S. K. Debsarma, *Climate Change in Bangladesh – A Statistical Review,* Report of IOC-UNEP Workshop on Impacts of Sea Level Rise due to Global Warming, Dhaka: Intergovernmental Oceanographic Commission, 1992.
[8] N. M. Mia, "Variations of temperature in Bangladesh", *Proceedings of SAARC Seminar on Climate Variability in the South Asian Region and its Impacts*, Dhaka: SAARC Meteorological Research Centre, 2003.
[9] S. Karmakar, and J. Nessa, "Climate Change and its Impacts on Natural Disasters and South-west Monsoon in Bangladesh and the Bay of Bengal", *Journal of Bangladesh Academy of Sciences*, Vol. 21, No. 2, 1997, pp. 127-136.
[10] S. Karmakar, "Trends in the annual frequency of cyclonic disturbances and storms in the Bay of Bengal", *Proceedings of SAARC Seminar on Climate Variability in the South Asian Region and its Impacts*, Dhaka: SAARC Meteorological Research Centre, 2003.
[11] M. Z. Haque, H. A. Quayyam, M. M. Hossian and M. S. Islam, "Occurrence of grain sterility in different rice crops", in A. K. M .N. Islam, Q. A. Fattah, I. A. Muttaqi and A. Aziz (eds.), *Plant Science and Man: Problems and Prospects*, Proceedings of International Botanical Congress, Dhaka: Bangladesh Botanical Society, 10-12 January 1991, pp. 117-124.
[12] M. H. K. Chowdhury and S. K. Debsarma, *op. cit.*
[13] Warrick *et al*., *op. cit*.

this period, Bangladesh was getting warmer. Since the later part of the last century, there has been, on average, an overall increase in temperature by 0.5^{0}C which was comparable to the observed global warming. Karmaker and Nessa[14] studied on climate change and its impacts on natural disasters and southwest-monsoon in Bangladesh and the Bay of Bengal. They found that the decadal mean annual temperature over Bangladesh has shown an increasing trend especially after 1961-1970.

Currently, there is no empirical literature to examine the effect of climatic variables on economic growth of Bangladesh with long term time series data. If the negative linkage between climate change and economic growth is found, it would indicate that Bangladesh could have achieved higher growth than the observed ones. Therefore, it would help the government and non-government actors to decide over their programmes on climate change. Given the context, this present study aims to find out whether there is any linkage of climate change variables on economic growth. This paper would add significant value to this aspect. Thus, the contributions of this paper are as follows. First, it accumulates the literature on the specific macro-economic variables and climate change. Second, it has used time series econometric techniques for a reasonable period, which provides useful insight for policymaking and undertaking future studies. The paper has been organised as follows. After the introduction, a comprehensive review of literature is presented in section 2. Section 3 describes the methodology of conducting the empirical study. Section 4 describes the results and analysis of the empirical findings. Finally, section 5 concludes the paper.

2. A Review of Literature

Empirical literature on the effect of climatic variables on economic growth of Bangladesh is sparse. However, the existing geophysical studies mostly concentrate on the change of temperature, rainfall and SLR to present evidences of climate change. Some studies also cover the geophysical variables of climate change and their impacts on GDP growth. Few of them also examine the effect of climate change on sectoral GDP.

Islam[15] presented a regional climate model named Providing Regional Climates for Impacts Studies (PRECIS) in generating rainfall scenarios for South Asia. At first, PRECIS generated rainfall scenario is calibrated with ground-based observed rainfall during baseline period (1961-1990) in Bangladesh. The regression coefficients obtained through calibration are utilised for validation of PRECIS simulated rainfall during 2000-2006. PRECIS overestimated rainfall by 12.37, 1.58, 10.81, 4.79 and 13.18 per cent in 2000, 2002, 2003, 2005 and 2006, respectively. It underestimated by

[14] S. Karmakar, and J. Nessa, *op. cit*.
[15] M. N. Islam, "Rainfall and Temperature Scenario for Bangladesh", *Open Atmospheric Science Journal*, Vol. 3, No. 1, 2009, pp. 93-103.

0.64 per cent and 10.84 per cent in 2001 and 2004, respectively. On average, PRECIS overestimated about 4.47 per cent of surface rainfall. Better performance of PRECIS through validation encouraged utilising it in rainfall forecasting for Bangladesh. In the second step, rainfall and temperature forecast for Bangladesh is experimentally obtained for 2010-2020. This work reveals that the PRECIS simulated rainfall and temperature are not directly useful in application purposes. However, after performing calibration, acceptable result obtained in estimating annual rainfall in Bangladesh with correlation coefficient is 0.9. Change of rainfall is forecasted from -0.99 per cent (in 2013) to 5.3 per cent (2018) for Bangladesh from 2010 to 2020.

Basak *et al.*[16] assessed climatic variability based on analysis of historical data of temperature and rainfall recorded at 34 meteorological stations located at seven regions in Bangladesh for the period of 1976-2008. The trend of variation of yearly average maximum temperature has been found to be increasing at a rate of 0.0186°C per year, whereas the rate was 0.0152°C per year for yearly average minimum temperature. Analysis of monthly average maximum temperature also showed increasing trend for all months except January and April. The increasing trend was particularly significant for May to September and for February. Monthly average minimum temperature data also showed increasing trends for all months except January and November. Analysis of rainfall data showed that for a large majority of stations, the total rainfall showed increasing trend for monsoon and post-monsoon seasons, while decreasing trend was observed for the winter; pre-monsoon rainfall did not show any significant change. These observations are particularly significant in the context of Bangladesh where agriculture is heavily dependent on temperature and rainfall patterns.

Rajib *et al.*[17] presented the development of multi-model combination of future surface temperature projections for Bangladesh on monthly basis, for each of the year from 2011 to 2100, using both global and regional climate models. The study demonstrated evidence of increasing temperature levels in Bangladesh from the climate model projections based on observed meteorological data. From the multi-model combination, Regional Climate Model (RCM) and Global Climate Model (GCM) projections of future average temperature change with respect to 1971-2000, it demonstrated that the winter months in Bangladesh might show more warming in future than the monsoon and pre-monsoon months. However, the trend of temperature increase might continue to increase invariably in every month.

Hasan and Rahman[18] studied the trend of temperature in Bangladesh. Long term changes in surface air temperature over Bangladesh have been studied using

[16] J. K. Basak, R. A. M. Titumir, and N. C. Dey, "Climate Change in Bangladesh: A Historical Analysis of Temperature and Rainfall Data", *Journal of Environment*, Vol. 2, No. 2, 2013, pp. 41-46.
[17] M. A. Rajib, M. M. Rahman, and E. A. McBean, "Global Warming in Bangladesh Perspective: Temperature Projections upto 2100", *Proceedings of the Global Conference on Global Warming*, Lisbon, 11-14 July 2011.
[18] A. B. M. S. U. Hasan and M. Z. Rahman, "Change in Temperature over Bangladesh Associated with Degrees of Global Warming", *Asian Journal of Applied Science and Engineeri*ng, Vol. 2, No. 2, 2013, pp. 62-75.

the available historical data collected by the Bangladesh Meteorological Department (BMD). The maximum, minimum and mean monthly temperature data of sixty-three years (1948-2010), collected from 35 stations of BMD located all over Bangladesh, have been used in this study. It has been found that monthly maximum temperature shows a positive trend of increase at a rate of 0.5°C per 100 years. The maximum increase occurred during November at a rate of 2.05°C per 100 years. However, monthly minimum temperature shows statistically significant trend of increase at a rate of 1.40°C per 100 years. Monthly mean temperature shows a positive trend of increase at a rate of 0.8°C per 100 years. It clearly indicates that monthly minimum temperature has increased significantly during the winter season (October to February) over the last sixty-three years. It also reveals that temperature was increasing predominantly over 21 years (1990-2010) than 63 years (1948-2010).

Being a low-lying deltaic country, Bangladesh is exposed to serious consequences of sea-level rise including permanent inundation of huge land masses along the coast line. There is a clear evidence of changing climate in Bangladesh which is causing changes in the precipitation, increasing annual mean temperature and sea-level rise. Shamsuddoha and Chowdhury[19] found that during a period from 1961 to 1990, the annual mean temperature increased at the rate of 0.0037°C but the rate was 0.0072 during 1961 to 2000. It means that in the 1990s, annual mean temperature rise was almost double than the previous years. Over the last 100 years, Bangladesh has warmed up by about 0.5°C and 0.5 metre rise of sea-level in the Bay of Bengal. The study reveals that the loss of decreasing productivity, which is assuming 28 to 57 per cent reduction of crop production from the present level by 1 metre sea-level rise, cannot be restored.

Karim and Mimura[20] described the impacts of Sea Surface Temperature (SST) rise and sea-level rise (SLR) on cyclonic storm surge flooding in western Bangladesh. A calibrated numerical hydrodynamic model was used to simulate surge wave propagation through the rivers and overland flooding. The model was calibrated with base condition (present climate), and then eight flooding scenarios of plausible future conditions were assessed by considering increased surge heights. Flooded area, flooding depth and surge intrusion length were computed by superimposing the predicted maximum water level information on a Digital Elevation Model (DEM). This analysis showed that for a storm surge under 2°C SST rise and 0.3 metre SLR, flood risk area would be 15.3 per cent greater than the present risk area and depth of flooding would increase by as much as 22.7 per cent within 20 km from the coastline. Within the risk area, the study identified 5,690 km^2 land (22 per cent of exposed coast) as a high-risk zone (HRZ) where flooding of depth 1 metre or more might occur, and people should move to nearby cyclone shelters during extreme cyclonic events.

[19] M. Shamsuddoha, and R. K. Chowdhury, *Climate Change Impact and Disaster Vulnerabilities in the Coastal Areas of Bangladesh*, Dhaka: COAST Trust, 2007.

[20] M. F. Karim and N. Mimura, "Impacts of climate change and sea-level rise on cyclonic storm surge floods in Bangladesh", *Global Environmental Change*, Vol.18, No.3, 2008, pp. 490-500.

Predicted area of HRZ is 1.26 times compared to the currently demarcated HRZ. It was estimated that 320 additional shelters are required to accommodate people in the newly identified HRZ. This information would be of value to policy and decision makers for future shelter planning and designing shelter heights.

Islam *et al.*[21] examined the vulnerabilities of agriculture in coastal regions of Bangladesh to the different adverse effects of sea-level rise induced hazards, and also identified option for future agricultural adaptations. It reveals that due to sea-level rise, agriculture of the study area has already experienced noticeable adverse impacts especially in terms of area of inundation, salinity intrusion and reduction in crop production. A total of 303 out of 1200 respondents from three coastal villages were randomly interviewed. Descriptive and inferential statistics and logistic regression have been conducted to analyse the data. The study found that the agricultural land, production of crops, local crop varieties, income and employment facilities of the farmers are highly vulnerable to various SLR induced hazards. Selection of various adaptation options, such as control of saline water intrusion into agricultural land, coastal afforestation, cultivation of saline tolerant crops, homestead and floating gardening, embankment cropping and increase of income through alternative livelihoods are emerging need for sustainable coastal agricultural development. Therefore, this paper argued that further development and implementation of such adaptive measures could help minimise vulnerabilities of agriculture in the long run.

World Bank[22] assessed the impacts of predicted climate changes on crop yields, agricultural production and GDP by factoring in all climate impacts, *viz*. CO_2 emission, temperature and precipitation changes, flooding, and sea-level rise. It reveals that cumulative loss of rice production would be 80 million tons, which is nearly 3.9 per cent per year over 2005-50. Agricultural GDP is projected to decline annually by 3.1 per cent, *i.e.*, US$ 36 billion value-added in agriculture is lost, while the loss of total GDP is estimated to be US$ 129 billion over this period.

Ahmed and Suphachalasai[23]used global PAGE model and Bangladesh-specific Computable General Equilibrium (CGE) model to assess the effects of climate change on GDP. It reveals that by 2050, annual GDP losses under the business as usual scenario is projected to be only 2 per cent while due to inaction (*i.e.*, no action is taken for adaptation), the average total economic losses are estimated to be 9.4 per cent.

The above discussion reveals that the studies on the effects of climate change of Bangladesh are based on global geophysical and CGE models. None of them use

[21] M. A. Islam, P. K. Shitangsu and M. Z. Hassan, "Agricultural vulnerability in Bangladesh to climate change induced sea level rise and options for adaptation: a study of a coastal Upazila", *Journal of Agriculture and Environment for International Development*, Vol. 109, No. 1, 2015, pp. 19-39.

[22] World Bank, *The Economics of Adaptation to Climate Change*, Washington, DC: World Bank, 2010.

[23] M. Ahmed and S. Suphachalasai, *Assessing the Costs of Climate Change and Adaptation in South Asia*, Manila: Asian Development Bank, 2014.

long-term time series data on major climatic variables, *viz.*, greenhouse gas emission, rainfall and temperature to examine their effects on long term GDP growth of the country. The CGE models are primarily based on Social Accounting Matrix (SAM) for a specific point of time, which is unable to capture the dynamics of co-movement of GDP and geophysical data. The present paper is an attempt to address these limitations.

3. Methodology and Data

The objective of the present paper is to empirically examine the effects of climatic variables on economic growth in Bangladesh. Here, annual change of GDP is taken as economic growth variable, while greenhouse gas emission, rainfall and temperature are taken as climate change variables. Thus, the econometric model used for the paper is as follows:

$$\Delta GDP_t = \beta_0 + \beta_1 GHG_t + \beta_2 Rain_t + \beta_3 Temp_t + \varepsilon_t \quad (1)$$

where

ΔGDP = Annual change of GDP at constant 2010 US dollars

Δ = first difference operator

GHG = Total greenhouse gas emissions (kiloton of CO_2 equivalent);

Rain = Average annual rainfall (in millimetre);

Tem = Average annual temperature (0 Celsius);

εit = Random error term with usual statistical properties;

β_0 = the constant term in the model;

β_1, β_2 and β_3 = unknown parameters of the model to be estimated; and

t = Sample period from 1981 to 2015

Time-series econometrics requires an analysis of the time-series properties and paths of the economic variables in a regression equation before estimation of the model to consider if any relationship can be estimated for the model. To find out the long-term relationship among the variables, it is essential to have non-stationary at levels and stationary at first differences.

3.1 *Testing Stationarity*

Testing stationarity of the variables is important in the time series before proceeding forward to the analysis. While testing for stationarity of the variables, conventional unit root tests like Augmented Dickey Fuller (ADF) and the Phillip-Perron (PP) tests may present test statistics that are strongly misleading in the presence of structural breaks in the time series of the variables. If any result is inferred from them, it will be inaccurate. For example, in the event of a standard ADF regression:

$$y_t = \alpha + \partial_t + \sum_{j=1}^{p} \gamma_j \Delta y_{t-j} + \rho y_{t-1} + \varepsilon_t$$

A non-stochastic level shift will cause the primary coefficient of concern in the ADF regression, ρ, to be biased towards 1 while a change in the trend slope makes the estimator tend to 1 in probability as the sample size increases. Hence, the ADF test may infer the presence of unit root even when the time-series is stationary around the deterministic break component. In fact, such blemishes may be extended to other modules of traditional unit root tests too, as suggested by Perron[24], Zivot and Andrews[25], and Perron and Vogelsang.[26]

Phillips and Perron[27] proposed nonparametric transformations of the τ (tau) statistic from the original DF regressions such that under the unit root null, the transformed statistics (the "z" statistic) have DF distributions. The results are also verified by PP test.[28] The regression for the PP test is

$$y_t = \beta_0 + \delta_t + \gamma_1 y_{t-1} + \sum_{j=0}^{\rho} \gamma_j y_{t-j} + \varepsilon_t$$

where δ_t may be 0, μ, or $\mu+\beta_t$ and ε_t is $I(0)$.

3.2 *Analysis of Structural Break*

In the case of this regression model that involves time series data, there may be a structural change in the relationship between the dependent and independent variables. Structural change implies that the values of the parameters of the model do not remain the same through the entire period. Sometimes the structural change may be due to external forces or to unobservable factors, which exert individual or combined impact on the country.

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[24] P. Perron, "The great crash, the oil price shocks, and the unit root hypothesis", *Econometrica*, Vol. 57, No. 6, 1989, pp. 1361-1401; and P. Perron, "Further evidence on breaking trend functions in macroeconomic variables", *Journal of Econometrics*, Vol. 80, No. 2, 1997, pp. 355-385.
[25] E. Zivot and D. W. K. Andrews, "Further evidence on the great crash, the oil-price shock, and the unit-root hypothesis", *Journal of Business and Economic Statistics*, Vol. 10, No. 3, 1992, pp. 251-270.
[26] P. Perron and T. J. Vogelsang, "Nonstationarity and level shifts with an application to purchasing power parity", *Journal of Business and Economic Statistics*, Vol. 10, No. 3, pp. 301-320.
[27] P. C. B. Phillips and P. Perron, "Testing for a unit root in time series regression", *Boimetrika*, Vol. 75, No. 2, 1988, pp. 335-346.
[28] *Ibid*.

A traditional approach of examining structural change is to adopt the Chow test.[29] This test assesses whether the coefficients in two linear regressions on different data sets are equal. The fundamental problem associated with this test is the arbitrariness of a researcher in bifurcating the series to examine whether two sets have different intercepts, slopes or both. Recent developments in the literature of structural break suggest that it is important to determine (i) whether there is structural break in the entire series or not by taking into account the time series properties of the data, and (ii) single or multiple breakpoint exists in a series, and (iii) the year of the structural break.

3.3 Existence of the Break

Elliott and Müller[30] devised a test to examine whether there is a structural break in a series. This test allows for many or relatively few breaks, clustered breaks, regularly occurring breaks, or smooth transitions to changes in the regression coefficients. The test distinguishes the null hypothesis of a stable regression model

$$y_t = X_t'\bar{\beta} + Z_t'\delta + \varepsilon_t \qquad t = 1, \ldots, T \qquad (2)$$

from the alternative hypothesis of the unstable model

$$y_t = X_t'\beta_t + Z_t'\delta + \varepsilon_t \qquad t = 1, \ldots, T \qquad (3)$$

with non-constant $\{\beta_t\}$, where y_t is a scalar, X_t, β_t are $k\times1$ vectors, Z_t and δ are $d\times1$, $\{y_t, X_t, Z_t\}$ are observed, $\bar{\beta}$, $\{\beta_t\}$, and δ are unknown, and ε_t is mean-zero disturbance. That is, this test examines whether the coefficient vector that links the observables X_t to y_t remains stable over time, while allowing for other stable links between y_t and the observables through Z_t. This very general specification nests many of the 'structural break' and 'time varying parameter' models in the literature, allowing for almost any pattern of variation in the coefficients of the X variables, with good power and size even in a heteroscedastic context.

Optimal Breakpoint

The Elliott-Müller test does not identify the optimal year of a break and whether there is one or more than one break year in a series. For examining the optimal breakpoint, two tests have been adopted: (i) Zivot-Andrews test and (ii) Clemente-Montañés-Reyes test.

[29] G. C. Chow, "Tests of Equality between Sets of Coefficients in Two Linear Regressions", *Econometrica*, Vol. 28, No. 3, 1960, pp. 591-605.

[30] G. Elliott and U. K. Müller, "Efficient Tests for General Persistent Time Variation in Regression Coefficients", *Review of Economic Studies*, Vol. 73, No. 4, 2006, pp. 907-940.

Zivot and Andrews[31] proceed with three models to test for a unit root: Model 4, which permits a one-time change in the level of the series; Model 5, which allows for a one-time change in the slope of the trend function, and Model 6, which combines one-time change in the level and the slope of the trend function of the series. To test for a unit root against the alternative of a one-time structural break, Zivot and Andrews use the following regression equations corresponding to the above three models:

$$\Delta y_t = c + \alpha y_{t-1} + \beta_t + \gamma DU_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t \quad (4)$$

$$\Delta y_t = c + \alpha y_{t-1} + \beta_t + \theta DU_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t \quad (5)$$

$$\Delta y_t = c + \alpha y_{t-1} + \beta_t + \theta DU_t + \gamma DU_t + \sum_{j=1}^{k} d_j \Delta y_{t-j} + \varepsilon_t \quad (6)$$

where DU_t is an indicator dummy variable for a mean shift occurring at each possible break-date (TB) while DT_t is the corresponding trend shift variable. Formally,

$$DU_t = \begin{cases} 1 & if \quad t > TB \\ 0 & otherwise \end{cases} \quad \text{and}$$

$$DU_t = \begin{cases} t - TB & if \quad t > TB \\ 0 & otherwise \end{cases}$$

The null hypothesis in all the three models is α=0, which implies that the series $\{y_t\}$ contains a unit root with a drift that excludes any structural break, while the alternative hypothesis α<0 implies that the series is a trend-stationary process with a one-time break occurring at an unknown point in time. The Zivot-Andrews test considers every point as a potential break-date (TB) and runs a regression for every possible break-date sequentially. From amongst all possible break-points (TB), the procedure selects as its choice of break-date ($\overline{TB}$) the date which minimises the one-sided t-statistic for testing $\hat{\alpha}$ =(α-1) =1. According to Zivot and Andrews, the presence of the end points causes the asymptotic distribution of the statistics to diverge towards infinity. Therefore, some regions must be chosen such that the end points of the sample are not included. They suggest the 'trimming region' be specified as (0.15T, 0.85T).

Also, it is imperative to examine whether there is more than one breaks. Following Clemente *et al.*[32], the null hypothesis can be tested as

[31] Zivot and Andrews, *op. cit*.

[32] J. Clemente, A. Montañés and M. Reyes, "Testing for a unit root in variables with a double change in the mean", *Economics Letters*, Vol. 59, No. 2, 1998, pp. 175-182.

$$y_t = y_{t-1} + \delta_1 DTB_{1t} + \delta_2 DTB_{2t} + u_t \qquad (7)$$

against the alternative hypothesis

$$y_t = \mu + d_1 DU_{1t} + d_2 DTB_{2t} + e_t \qquad (8)$$

where DTB_{it} is a pulse variable that takes the value 1 if $t=TB_i+1$ (i=1, 2) and 0 otherwise, $DU_{it}=1$ if $t>TB$ (i=1, 2) and 0 otherwise. TB_1 and TB_2 are the time periods when the mean is being modified. For simplicity, suppose $TB = \lambda_i T$ (i=1, 2), with $0<\lambda_i<1$ and $\lambda_2>\lambda_1$. Now, if the two breaks belong to the innovational outlier, the unit-root hypothesis can be tested by

$$y_t = \mu + \rho y_{t-1} + \delta_1 DTB_{1t} + \delta_2 DTB_{2t} + + d_1 DU_{1t} + d_2 DTB_{2t} + \sum_{i=1}^{k} c_i \Delta y_{t-i} + e_t \qquad (9)$$

Data

For the purpose of this paper, yearly data has been collected for the period 1981 to 2015. Data on GDP and GHG are taken from the World Development Indicators database.[33] Data on Rain and Temp are taken from the World Bank Climate Change Knowledge Portal.[34]

The econometric equation (1) is based on the presumption that variability in climate change indicators can sufficiently explain the variability in GDP growth of Bangladesh without considering the other factors, such as capital and labour. The paper avoids the production function approach, which is complicated due to lack of reliable data on the stock of capital. On the other hand, continuous annual data on labour force is also unavailable in the secondary sources. Therefore, the present exercise depends on the explanatory power of the climate change indicators based on the scores of the goodness of fit.

4. Results and Analysis

Before conducting the main multivariate analysis, stationarity tests have been performed to understand whether the variables included in the model are stationary (random) or not. If the variables are non-stationary at level, then the first difference needs to be taken and then again the tests have been conducted for stationarity. Afterwards, multivariate time series method should be applied to estimate the Equation (1). The results of stationarity test, *viz*. ADF and PP reported in Table 1, where both tests indicate that only total greenhouse gas emissions and temperature are found to be stationary.

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[33] Available at https://data.worldbank.org/indicator?tab=all, accessed on 02 September 2017.
[34] Available at http://sdwebx.worldbank.org/climateportal/index.cfm?page=country_historical_climate&ThisCCode=BGD, accessed on 02 September 2017.

Table 1: Results of the Unit Root Tests without structural breaks

	Level		First Difference		Remark
	ADF	PP	ADF	PP	
GDP	4.650	5.237	-3.853**	-4.161***	I(1)
GHG	0.067	0.394	-8.273***	-8.238***	I(1)
Rain	-5.715***	-6.718***	-10.343***	-14.477***	I(0)/I(1)
Temp	-3.017**	-3.490**	-6.745***	-7.069***	I(1)

***, ** and * imply that the test statistic is significant at 1, 5 and 10 per cent level, respectively.

The Zivot Andrews model is used to detect one endogenous structural break for the unit root tests. The results are shown in Table 2. The last column shows that GDP as well as all independent variables fail to reject the null hypothesis of the unit root. This finding shows that all sample variables are stationary.

Table 2: Unit Root Test with One Endogenous Structural Break: Zivot-Andrews Test

	Level (Constant & Trend)	Break Point (Level)	1st Difference (Constant & Trend)	Break Point (1st Difference)	Remarks
GDP	-2.054	1999	-9.008***	2005	I(1)
GHG	-5.253**	1998	-9.189***	2007	I(1)
Rain	-7.444***	2001	-7.436***	1995	I(0)/I(1)
Temp	-4.966	2009	-7.149***	2012	I(1)

*** and ** imply that the test statistic is significant at 1, 5 and 10 per cent level, respectively.

Again, the Clemente-Montañés-Reyes test is employed to address the issue of the results of the unit root tests in the Zivot-Andrews model by considering the maximum of two structural breaks in the data series for the unit root tests. The results are presented in Table 3. The last column shows that only the total greenhouse gas emissions rejects the null hypothesis of the unit root for all series data in the sample.

Table 3: Unit Root Test with Two Endogenous Structural Breaks: Clemente-Reyes Test

	Min t in Level	Break Point (Level)	Min t in 1st Difference	Break Point (1st Difference)	Remarks
GDP	1.833* 2.631**	BP1= 1990 BP2= 2003	4.648*** 6.478***	BP1= 1988 BP2= 2003	I(1)
GHG	1.773* 1.924*	BP1= 1998 BP2= 2004	2.772*** -3.423***	BP1= 1997 BP2= 2011	I(1)

Rain	-3.423* -2.183*	BP1= 1990 BP2= 1999	-1.129 0.878	BP1= 2000 BP2= 2006	I(0)
Temp	2.483** -3.049***	BP1= 2003 BP2= 2011	-0.227 -3.179***	BP1= 1990 BP2= 2009	I(0)

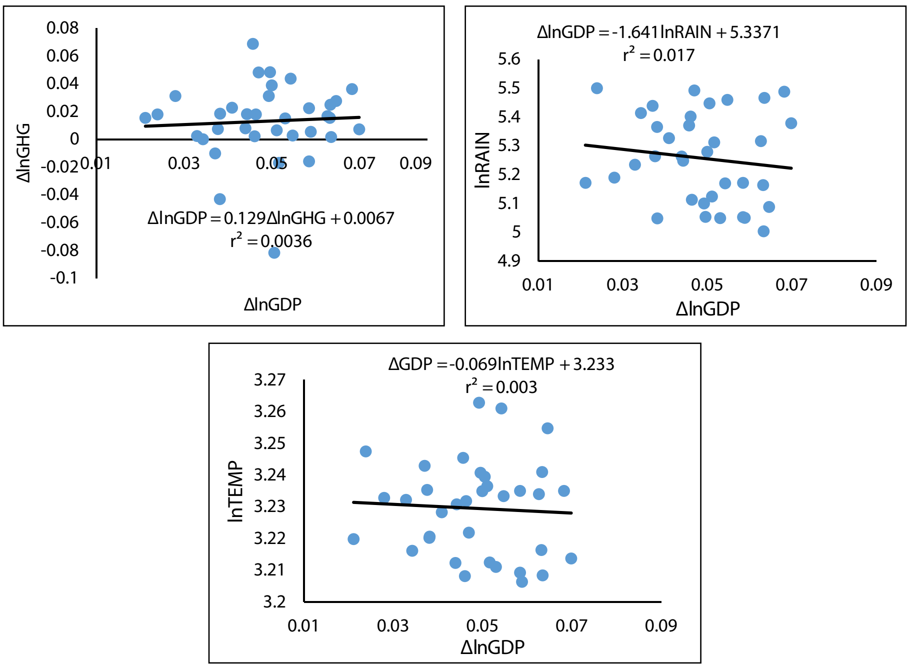
*** and ** imply that the test statistic is significant at 1, 5 and 10 per cent level, respectively.

Based on the above test results, the revised empirical equation can be written as follows:

$$ln\Delta GDP_t = \beta_0 + \beta_1 ln\Delta GHG_t + \beta_2\, lnRain_t + \beta_3\, lnTemp_t + \varepsilon_t \qquad (1a)$$

where *ln* is natural log to remove heteroscedasticity and autocorrelation form the variables.

Figure 1: Linkage between Climate Change Variables and GDP Growth



The present paper adopts the ARDL model suggested by Pesaran *et al.*[35], and Narayan and Narayan.[36] It allows both *I*(0) and *I*(1), which provides accurate estimates

[35] M. H. Pesaran, Y. Shin and R. J. Smith, "Bounds Testing Approaches to the Analysis of Level Relationships", *Journal of Applied Econometrics*, Vol. 16, No. 3, 2001, pp. 289-326.
[36] P. K. Narayan and S. Narayan, "Estimating Income and Price Elasticities of Imports for Fiji in a Cointegration Framework", *Economic Modelling*, Vol. 22, No. 3, 2005, pp. 423-438.

of short-and long-term parameters of the specified model, which is befitting with the present paper because it has both *I*(0) and *I*(1) series. It also provides valid *t*-statistics in the occurrence of endogenous variables in the model.[37] The estimated parameters and test statistics based on an ARDL model are super-consistent, which can be used to draw valid inferences for the parameters.[38]

Contributed notably by Pesaran and Shin,[39] and Pesaran *et al.*[40], an autoregressive distributed lag (ARDL) model of order *p* and *q*, denoted by ARDL(*p,q*) regresses the dependent variable on *p* of its own lags and on *q* lags of one or more additional regressors. Multiple regressors are allowed to contain different lag orders, where the model becomes an ARDL ($p, q_1, ..., q_k$) model with *k* number of non-deterministic regressors. ARDL models can also be used for the estimation and testing of cointegrating relationships with bounds *F*, W and *t* tests.[41] Thus, the augmented ARDL ($p, q_1, q_2, \ldots, q_k$) model, suggested by Pesaran *et al.*[42], can be written as:

$$\varphi(L, p) y_t = \sum_{i=1}^{k} \beta_i (L, q_i) x_{i,t} + \delta' w_t + u_t \quad ; t = 1, 2, \ldots, 27 \tag{10}$$

where, *L* is the lag operator with $Ly_t = y_{t-1}$; w_t is $s \times 1$ vector of deterministic variables; $p = 0,1,2, \ldots, m$; $q_i = 0,1,2, \ldots, m$; $\varphi(L,p) = 1 - \varphi_1 L - \varphi_2 L^2 - ... - \varphi_p L^p$; $\beta_i (L, q_i) = 1 - \beta_{i1} L - \beta_{i2} L^2 - ... - \beta_{iq_i} L^{q_i}$. The long-term estimator for the response of dependent variable to a unit change in independent variables can be written as

$$\hat{\theta}_i = [\hat{\beta}_i (1, \hat{q}_i)] / \hat{\varphi}(1, \hat{p})]$$

The long-term estimator is

$$\hat{\psi} = [\hat{\delta}(\hat{p}, \hat{q}_i)] / [\hat{\varphi}(1, \hat{p})]$$

[37] B. Inder, "Estimating Long-Run Relationships in Economics: A Comparison of Different Approaches", *Journal of Econometrics*, Vol. 57, No. 1-3, 1993, pp. 53-68.

[38] M. H. Pesaran and Y. Shin, "An Autoregressive Distributed Lag Modelling Approach to Cointegration Analysis", *DAE Working Paper 9514*, Cambridge: University of Cambridge, 1995.

[39] M. H. Pesaran, and Y. Shin, "An Autoregressive Distributed Lag Modelling Approach to Cointegration Analysis", in S. Strom, (ed.), *Econometrics and Economic Theory in the 20th Century: The Ragnar Frisch Centennial Symposium*, Cambridge, UK: Cambridge University Press, 1999.

[40] Pesaran *et al.*, *op. cit*.

[41] For a succinct exposition of ARDL models in the context of cointegration, see U. Hassler, and J. Wolters, "Autoregressive Distributed Lag Models and Cointegration", *Allgemeines Statistisches Archiv*, Vol. 90, No. 1, 2006, pp. 59-74; and U. Hassler, and J. Wolters, "Autoregressive Distributed Lag Models and Cointegration", Working Paper No. 2005/22, Berlin: Freie Universitaet, 2005.

[42] Pesaran *et al*., *op. cit.*

In addition, the short term or the error correction representation of the ARDL($p, q_1, q_2, \ldots, q_k$) model is given by

$$\Delta y_t = -\varphi(1,\hat{p})EC_{t-1} + \sum_{i=1}^{k} \beta_{i0}\Delta x_{i,t} + \hat{\delta}\Delta w_t - \sum_{j=1}^{\hat{p}-1} \varphi_j^* \Delta y_{t-j} - \sum_{i=1}^{k}\sum_{j=1}^{\hat{p}-1} \beta_{ij}^* \Delta x_{i,t-j} + u_t \quad (11)$$

where $EC_t = y_t - \sum_{i=1}^{k} \hat{\theta}_i x_{i,t} - \hat{\psi}' w_t$ is the error correction term; $\varphi(1,\hat{p})$ estimates the significance of the EC, and φ_j^* and β_{ij}^* are the parameters that capture the short-run dynamics of the model.

The empirical results of the ARDL model have been presented in Tables 4 to 7. The short-term coefficients shown in Table 4 are as per the expectations. The results reveal that greenhouse gas emission in the present period has a positive linkage with GDP growth. It is perhaps obvious because higher output leads to greater emission of the greenhouse gas. However, the lagged greenhouse gas emission is negatively associated with GDP growth. It may be because of its adverse effects through increasing temperature and erratic rainfall, which have negative association with GDP growth at the present and immediate past periods. The empirical model shows correct form in all the diagnostic tests. Values of R^2, adjusted R^2 and F statistic indicate that the independent variables have sufficient power to explain the empirical model, which validate the adoption of econometric equation (1).

Table 4: ARDL (0,2,2,2) Estimates based on Schwarz Bayesian Criterion

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
GHG	0.093	0.054	1.727 [0.097]
GHG (-1)	-0.105	0.055	-1.904 [0.069]
GHG (-2)	-0.163	0.053	-3.024 [0.006]
Rain	-0.004	0.008	-0.439 [0.664]
Rain (-1)	-0.056	0.008	-6.811 [0.000]
Rain (-2)	-0.029	0.007	-3.747 [0.001]
Temp	-0.149	0.085	-1.737 [0.095]
Temp (-1)	-0.292	0.132	-2.198 [0.038]
Temp (-2)	0.601	0.102	5.873 [0.000]
R^2	0.767		
Adjusted R^2	0.689		

F(8,24)	9.871 [0.000]		
A. Serial Correlation $\chi^2(1)$	1.174 [0.279]		
B. Functional Form $\chi^2(1)$	0.5193E-3 [0.982]		
C. Normality $\chi^2(2)$	1.493 [0.475]		
D. Heteroscedasticity $\chi^2(1)$	2.119 [0.146]		

A: Lagrange multiplier test of residual serial correlation
B: Ramsey's RESET test using the square of the fitted values
C: Based on a test of skewness and kurtosis of residuals
D: Based on the regression of squared residuals on squared fitted values
Source: Author's estimation with Microfit 5.0.

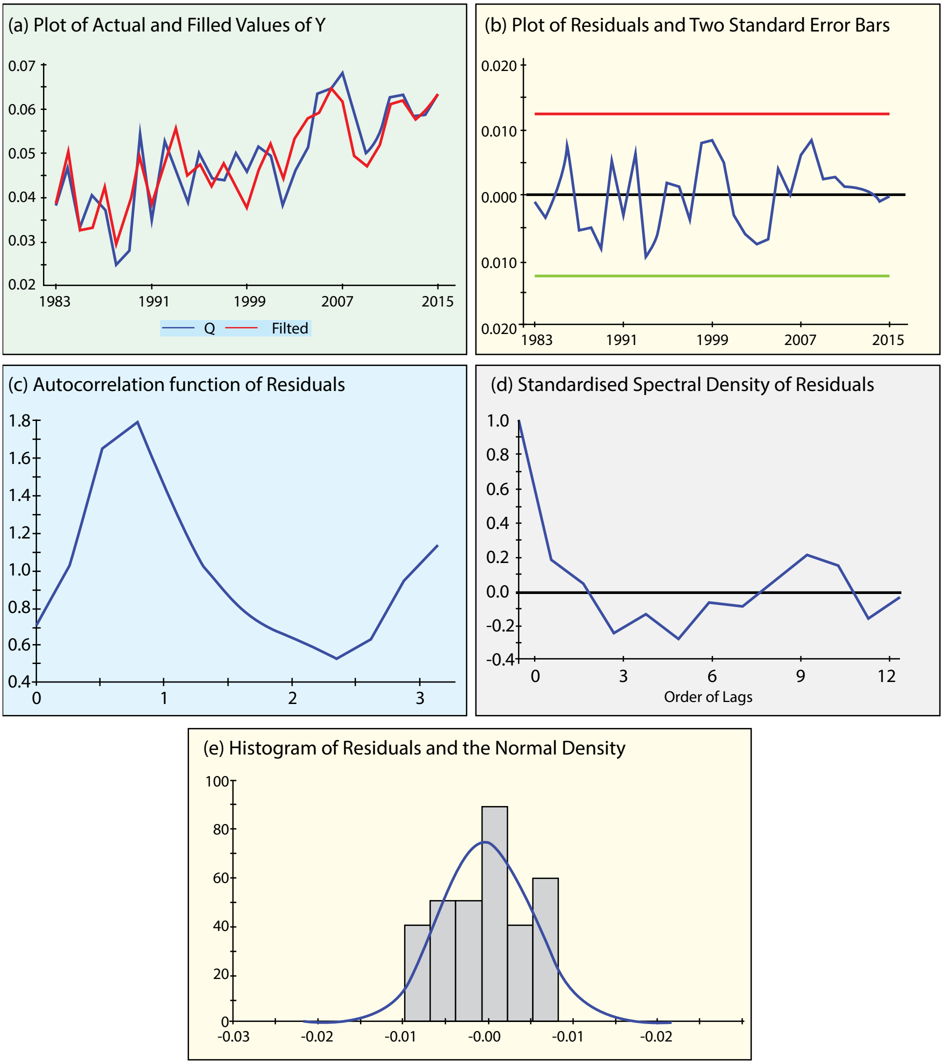
The long-term coefficients have been presented in Table 5. It reveals that greenhouse gas emission and rainfall variables have negative and statistically significant impact on GDP growth of Bangladesh. However, the temperature coefficient has been found to be positive, which may be ignored because greenhouse gas emission is linked with temperature growth.

Table 5: ARDL (0,2,2,2) Long Run Estimates based on Schwarz Bayesian Criterion

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
GHG	-0.175	0.108	-1.616 [0.100]
Rain	-0.088	0.013	-6.624 [0.000]
Temp	0.160	0.022	7.259 [0.000]

The results reported in Tables 4 and 5 have been checked with the short and long-term coefficients of ARDL model with lag specified by Akaike Information Criterion to examine the sensitivity of the results. Reported in Table 6, the results indicate that in the short-run, the sign and statistical significance of all variables match with the results based on Schwarz Bayesian Criterion except the coefficient of GHG. The long run parameters of Table 7 also match with the results of Table 5 except GHG.

Figure 2: Results after Estimating ARDL Model



Source: Microfit 5.0 output.

Table 6: ARDL (1,2,2,2) Estimates based on Akaike Information Criterion

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
GDP (-1)	0.153	0.123	1.235 [0.229]
GHG	0.077	0.055	1.396 [0.176]
GHG (-1)	-0.104	0.054	-1.898 [0.070]
GHG (-2)	-0.144	0.055	-2.593 [0.016]
Rain	-0.003	0.008	-0.403 [0.690]
Rain (-1)	-0.051	0.008	-5.949 [0.000]
Rain (-2)	-0.023	0.009	-2.487 [0.021]
Temp	-0.152	0.084	-1.802 [0.085]
Temp (-1)	-0.244	0.136	-1.788 [0.087]
Temp (-2)	0.538	0.113	4.751 [0.000]
R^2	0.781		
Adjusted R^2	0.695		
F(8,24)	9.137 [0.000]		
A. Serial Correlation $\chi^2(1)$	0.012 [0.910]		
B. Functional Form $\chi^2(1)$	0.152 [0.696]		
C. Normality $\chi^2(2)$	1.406 [0.495]		
D. Heteroscedasticity $\chi^2(1)$	1.588 [0.208]		
Bounds F-stat	12.617		
Bounds W-stat	50.471		

Bounds: F-statistic lower and upper 95% =2.7197,4.0149; W-statistic lower and upper 95% =10.8789,16.0594

Table 7: ARDL (0,2,2,2) Long Run Estimates based on Akaike Information Criterion

Regressor	Coefficient	Standard Error	T-Ratio[Prob]
GHG	-0.201	0.128	-1.565 [0.131]
Rain	-0.092	0.016	-5.767 [0.000]
Temp	0.166	0.026	6.298 [0.000]

According to Pesaran *et al.*[43] if the statistic lies between the bounds, the test is inconclusive. If it is above the upper bound, the null hypothesis of no level effect is rejected. If it is below the lower bound, the null hypothesis of no level effect cannot be rejected. The critical value of bounds F and t are computed by stochastic simulations using 20,000 replications in Stata 13 to check with the results of Microfit 5.0. The lower and upper bounds for F test at 1 per cent level are 4.29 and 5.61, respectively, while the same for *t*-test are –3.43 and –4.37, respectively. Thus, in both bounds *F* and *t* tests

[43] Pesaran *et al*., *op. cit*.

it has been found that a level relationship among the variables in the ARDL model, and examining the effect of climate change on GDP growth of Bangladesh with ARDL model is valid.

5. Concluding Remarks

The main purpose of this paper is to examine the impact of climate change on economic growth in Bangladesh. In doing so, it took some important climatic variables, *viz*. greenhouse gas emission, average annual rainfall and temperature over the period of three and a half decades, while annual change in GDP is taken as the indicator of economic growth. It conducted time series analysis to examine the stationarity and structural break of the variables. The Zivot-Andrews model is used to detect one endogenous structural break for the unit root tests and Clemente-Montañés-Reyes test is employed to address the issue of the results of the unit root tests in the Zivot-Andrews model by considering a maximum of two structural breaks in the data series for the unit root tests. Since the variables are both I(0) and I(1), the appropriate multivariate econometric model was ARDL. The lag length of the ARDL model is based on Schwarz Bayesian Criterion and Akaike Information Criterion. The empirical results suggest that all climatic variables have negative impact on the economic growth in their first lag. More specifically, according to the econometric findings, greenhouse gas emission, temperature and rainfall of the immediate past year exert negative influence on economic growth of the current year. The results of the present paper reinforce the previous findings that climate change indicators exert negative and statistically significant influence on economic growth of Bangladesh.