ECONOMIC IMPACT OF CLIMATE CHANGE ON WHEAT PRODUCTIVITY IN BANGLADESH: A RICARDIAN APPROACH

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Abstract

The study measured the economic impacts of climate change on wheat production in Bangladesh using Ricardian approach. Panel data on wheat yield and climate variables were used to estimate the model. Results indicated that most climate variables had a significant impact on the net revenue per hectare of wheat production. The increasing temperature marginally during January and February reduced the net revenue by Tk.18,885/ha and Tk. 9,603/ha respectively, whereas increasing temperature marginally during December increased it by Tk.7,045/ha. Increasing rainfall during December and January increases the net return by Tk.128/ha and Tk.543/ha respectively. The decreased net revenues ranged from 2.91 to 24.77% and increased net revenues ranged from 5.71 to 113.34% were estimated under A2 emission scenarios during 2030 and 2050 respectively. Under B1 emission scenarios, the decreased net revenues ranged from 0.36 to 4.59% and increased net revenues ranged from 1.05 to 18.58% during 2030, whereas the net revenue decreased 32.5% during 2050.

Keywords: Climate change; impacts; wheat; Bangladesh; Ricardian model.

1. Introduction

Climate change is now widely recognized as a phenomenon which is threatening for current way of our life on earth. One of the manifestations of climate change is fluctuations in the long term temperature in different seasons. According to a UNDP report, in 2005, Bangladesh, India and Pakistan faced temperatures 5–6°C above the regional average (UNDP, 2008). The average warming in annual temperature in the Himalaya and its vicinity between 1977 and 1994 was 0.06ºC per year (Shrestha *et al*., 1999). Climate related changes are observed in the long term data on precipitation patterns, temperature, intensity of severe floods, cyclones, landslides, erosion and sedimentation. Climate change is a major concern for developing countries like Bangladesh because of its tremendous social, environmental and economic consequences. These events affect and threaten livelihoods of millions of people in the developing countries through changes in agro-ecosystem and direct threats such as loss of land, crop productivity, livestock and household assets.

Growing body of literature suggests that climate change will significantly affect agriculture sector in developing countries and this may have serious consequences on the level of food production and food security, and would adversely affect huge population, with larger impacts on poor and small holder farmers, especially in developing countries like Bangladesh. Analysis of climate data of Bangladesh depicts that there is temporal and spatial variability in the rate of change and nature of resulting impacts affecting all sphere of life (Islam, 2009). In the Bangladesh context, the vulnerability is particularly high because of its large population and economic dependence on primary natural resources, being an agrarian economy. Having recognized the potential impacts of climate change as a long-term threat to agriculture sector, bulk of impacts studies are available for developed countries, while little is known about potential impacts in Bangladesh.

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2. Rationale of the study

In the 70s wheat was a minor cereal crop in Bangladesh but today it is the second most important cereal crop in terms of both production and consumption. It is produced all over the country during the winter season. Wheat farmers are also vulnerable to climate change since the production of wheat is highly sensitive to temperature. Agronomic studies in India suggest that a temperature rise of 4^0C would reduce grain yields by 25-40% (Rosenzweig and Parry, 1994) and wheat yields by 30-35% in the absence of adaptation and carbon fertilization (Kumar and Parikh, 1998). IPCC fourth assessment report mentions climate change could decrease agricultural productivity in South Asia up to 30% by mid-21st century. Therefore, the country has to import a huge amount of wheat every year from different countries. It is also reported that the possibility of food imports by developing countries will be increased manifolds due to climate change (IPCC, 2007).

Mendelsohn *et al.* (2009) measured the impact of climate change on overall agricultural in Bangladesh using Ricardian model but no empirical study regarding the estimation of climate impacts on wheat production is available on Bangladesh. This study will contribute towards existing knowledge gap, and help researchers and policy makers to respond to climate change by adjusting agricultural and environmental policies and practices as needed. In particular, we have the following two hypotheses to be tested in this research.

3. Hypotheses:

1. Temperature and rainfall would affect the wheat production in Bangladesh.
2. Forecasted climate change scenarios will have significant impacts on wheat production in Bangladesh.

4. Study Approach and Methods

The Ricardian log linear model used in this study is an empirical approach developed by Mendelsohn *et al.* (1994) to measure the economic impact of climate change on wheat production in Bangladesh. The method was named after Ricardo[1] because of his original observation that the value of land would reflect its net productivity at a site under perfect competition. This approach estimates the impact of climate and other variables on land values and farm revenues, and has been widely used in different studies (Mendelsohn, Nordhaus, and Shaw, 1994 & 1999; Cline, 1996; Sanghi and Mendelsohn, 1999; Darwin, 1999; Gbetibouo and Hassan, 2005; Kabubo-Mariara and Karanja, 2007; Mendelsohn and Reinsborough, 2007; Kurukulasuriya and Ajwad, 2007).

The estimated changes in net productivity caused by changes in environmental variables are aggregated to the overall national impact (Olson et al. 2000) or incorporated into an economic model to simulate the welfare impacts of productivity changes under various climate change scenarios (Adams, 1989; Kumar and Parikh, 1998; Chang, 2002). This model makes it possible to account for the direct impact of climate change on crop yields and the indirect substitution among different inputs including the introduction of various activities, and other potential adaptations to a variety of climates by directly measuring farm prices or revenues (Derssa and Hassan, 2009). The weaknesses of the Ricardian approach are: it is not based on controlled experiments across farms; and it does not include price effects and carbon fertilization effect (Mendelsohn *et al*. 2009; Cline, 1996).

Using Ricardian technique, net revenue from per hectare of wheat production was regressed on climate variables to identify the role of climate in explaining net revenues. The contribution of each

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[1] In a competitive market, rents would be equal to the net revenue from the land (Ricardo, 1871).

factor to the farm performance (net revenue) was measured by regressing it on a set of climatic variables. Using net revenue per hectare of cropland as dependent variable is more robust measure since it measures what the farmer currently receives without any concerns for future returns, discounting, capital or labour market. The Ricardian approach involves specifying a net productivity function of the following form:

$$V = \sum_i P_i Q_i (X, C, Z) - \sum P_x X \quad \text{……………………..………………[1]}$$

Where, V is net revenue per hectare, P_i is the market price of crops, Q_i is the quantity of crops produced, X is a vector of purchased inputs (other than land), C is a vector of climate variables, Z is a vector of other control variables tied to the farm such as soils, and economic variables such as market access, and P_x is a vector of input prices. The farmer is assumed to choose X to maximize net revenues[2] given the characteristics of the farm and market prices. Solving Equation 1 leads to a reduced form model where net revenue becomes a function of all the exogenous variables, P_i, P_x, C, and Z;

$$V = R(P_i, P_x, C, Z) \quad \text{……………………………………………………………………[2]}$$

The empirical model used in this study was a log-linear specification of the Recardian model as shown below.

$$\ln V = \beta_0 + \beta_1 C + \beta_2 C^2 + \beta_3 P + \beta_4 P^2 + \varepsilon \quad \text{………………………………………[3]}$$

Where, C is a vector of seasonal temperatures, P is a vector of seasonal precipitation, and ε is an error term. Both linear and quadratic term for temperature and precipitation were introduced. In the log-linear functional form the linear coefficients provide estimates of the proportional change in V for a change in the climate variable and the quadratic terms for temperature and precipitation reflects the non-linear shape of the response function between net revenues and climate (Equation 3). As there is a known temperature where a particular crop grows best across the seasons, crops often exhibit a hill-shaped relationship with annual temperature.

The expected marginal impact of a single climate variable on farm net revenue evaluated at the mean of variable is:

$$(dV / dC_j) = (\beta_{1j} + 2\beta_{2j} \times C) \times V \quad \text{…………………………………………………………[4]}$$

The change in annual welfare, ΔW, resulting from a climate change from C_0 to C_1 can be measured as follows. If the change increases net income, it is beneficial and if it decreases net return it is harmful.

$$\Delta W = V\big|_{T1} - V\big|_{T0} \quad \text{…………………………………………………………………………[5]}$$

Where, V is the predicted net revenue per hectare from the estimated net revenue model under the future climate scenario, and T1 is the predicted level of climate variable (temperature or rainfall, in this case) and to is the normal average temperature under the current climate scenario, ΔW is the difference between the predicted value of the net revenue per hectare under the future climate scenario and the current climate scenario.

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[2] In Recardian analysis for climate change, farmers are assumed to be rational economic agents and maximize their profits by using land in declining order of fertility because of change in climate and soil quality (Polsky, 2003).

Data:

Panel data[3] regarding wheat yield and climate variables (i.e. temperature and rainfall) were used in this study to estimate the model. In order to calculate net revenue from wheat production per hectare, the last 10 years' (1999-2008) wheat area, total wheat production, input quantity, input prices, and output prices for 15 districts were taken into account in this study. The selected districts were Dinajpur, Rangpur, Pabna, Rajshahi, Bogra, Jessore, Khulna, Mymensingh, Dhaka, Faridpur, Sylhet, Comilla, Chittagong, Rangamati, and Barisal. Data on production inputs, crop output, and farm revenues were compiled from different sources- BBS, DAE, DAM, WRC, etc.

Weather data corresponding to 15 meteorological stations spread across Bangladesh were interpolated for the purpose of developing the district specific climate data (see Kumar and Parikh, 2001b and Dinar *et al*., 1998, for more details on the surface interpolation employed to generate district level climate data). Climatic variables for the past 39 years (1950-1998) from all the 15 districts were used to capture the climate change effects over time and space. Monthly climate data (i.e. temperature and rainfall) were divided into a number of variables according to wheat season. Since temperature and rainfall are critical to wheat production and there are certain critical periods, the average temperature and rainfall for December, January and February over the period 1950-1998 for each of the 15 districts represent the climate variables used in this study. This is done based on the discussion with the agronomists. Thus, these data points do not vary over time but instead vary across districts.

5. Results of the Economic Impact Analyses

Net revenue for wheat was calculated by deducting total cost of cultivation from gross revenue of wheat (value of grain and straw). Table 1 presents the summary statistics of variables included in the Ricardian model. The average observed net revenue of wheat cultivation was estimated at Tk. 9989.98 per hectare. The net revenues ranged from Tk.1015 to Tk.36334 in the observations. The mean temperatures for December, January and February were 19.75°C, 18.52°C and 21.04°C respectively. The corresponding figures for rainfall were 9.10mm, 8.18mm and 18.43mm respectively. In these periods temperature and rainfall varied from 17.05°C to 22.60°C and 2.70m35.00mm respectively. Detailed climatic scenarios have been shown in Table 1.

The independent variables used in the model were linear and quadratic terms for climatic variables temperature and rainfall. Temperature rise play a crucial role in the growth as well as yield of wheat. It revealed that late seeding reduces the yield at the rate of 1.3% per day of delay after November 30 (Ahmed and Meisner, 1996). On the other hand, three irrigations are recommended for better yield since wheat is a winter crop. Based on the growing season and irrigation requirement, temperature and rainfall periods were divided into three variables (December, January and February). In the regression, temperature and rainfall were expected to have a negative and positive impact on net revenue of wheat respectively.

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[3]The same cross-sectional unit (say, a firm, state) is surveyed over time. In other words, pooling of time series and cross-sectional observations over time.

Table 1. Summary statistics of climate variables used in Ricardian model

Variables	Mean	St. Dev	Minimum	Maximum
A. Net revenue (Tk/ha)	9989.98	5150.6690	1015.00	36334.00
B. Temperature (in °C)				
December temperature	19.7476	0.7326	18.58	21.42
December temperature squared	390.4708	29.1303	345.38	458.60
January temperature	18.5156	0.8304	17.05	20.31
January temperature squared	343.4841	30.8099	290.70	412.29
February temperature	21.0353	0.8753	19.35	22.60
February temperature squared	443.2229	36.7464	374.25	510.70
C. Rainfall (in mm)				
December rainfall	9.1013	2.5611	3.83	16.41
December rainfall squared	89.3361	46.3389	14.63	269.35
January rainfall	8.1795	2.5549	2.70	13.70
January rainfall squared	73.3672	43.5101	7.29	187.69
February rainfall	18.4307	6.9578	3.53	35.00
February rainfall squared	387.9961	263.6461	12.43	1225.00

The regression results indicate that rise in December and February temperature reduce net revenue from wheat production and converse is also true. On the other hand, the coefficient for January temperature is positive and significant. It indicates that January temperature had positive impact on net revenue.

Table 2. Regression coefficients of climate variables over net revenue

Climate variable	Coefficients	Std. Err.	t-value	P>t
Constant	109.909**	43.84747	2.50	0.013
December temperature	-15.8907**	7.10096	-2.24	0.027
December temperature squared	0.4202**	0.17962	2.34	0.021
January temperature	20.2024**	7.91906	2.55	0.012
January temperature squared	-0.5966***	0.21357	-2.79	0.006
February temperature	-12.5097**	5.35939	-2.33	0.021
February temperature squared	0.3202**	0.12587	2.54	0.012
December rainfall	0.1748*	0.10433	1.68	0.096
December rainfall squared	-0.0089	0.00556	-1.60	0.111
January rainfall	0.1214	0.14578	0.83	0.406
January rainfall squared	-0.0041	0.00802	-0.51	0.613
February rainfall	-0.0539*	0.03238	-1.66	0.098
February rainfall squared	0.0016**	0.00078	2.07	0.040
N	150			
R^2	0.5272			
F (12, 137)	12.73***			

Note: Log of net revenue (Tk/ha) is dependent variable
'***' and '**' indicate significant at 1% and 5% level respectively

The coefficients for December and January rainfall are positive, whereas it is negative for February rainfall implying that December and January rainfall have positive and February has negative impact on net return per hectare (Table 2). However, the total impact of climate variables shall be interpreted as a whole considering both linear and quadratic terms and so the actual interpretations of the sign and magnitudes of impacts are further explained below under the marginal analysis.

5.1 Marginal Impact Analysis

The marginal impact analysis was undertaken to observe the effect of an infinitesimal change in temperature and rainfall on wheat farming in Bangladesh. The marginal impacts of temperature and rainfall have been shown in Table 3.

Table 3. Marginal Impact of climate change on net revenue per hectare

Period	Climate variable	
	Temperature	Rainfall
December	7,045**	128*
January	-18,885**	543
February	-9,603**	-51*

'***', '**', and '*' indicate significant at 1%, 5% , and 10% level respectively

5.2 The Impact of Forecasted Climate Scenarios

The impact of climate change on the net revenue per hectare was analyzed using the climate scenarios from the Special Report on Emission Scenarios (SRES). The SRES is a report prepared on future emission scenarios to be used for driving climate change models in developing climate change scenarios (IPCC, 2001). Two different SRES emission scenarios: A2 and B1 (Nakićenović, and Swart, 2000) were used for this analysis (Appendix table 1). The B1 scenario (most conservative) predicts only a small increase in greenhouse gas emissions and A2 scenario (business as usual) predicts a very large increase. Predicted values of temperature and rainfall from five climate models such as CCSM (Boville and Gent, 1998), ECHAM (Cubasch et al. 1997), GFDL (Manabe et al. 1991), MIROC (Tokioka et al., 1996), and HADCM3 (Gordon et al. 2000) were applied to predict the changes in climate in the decades around 2030 and the decades around 2050. Mendelsohn *et al.* (2009) also used these climate scenarios to estimate the impact of climate change on overall agriculture in Bangladesh.

By using parameters from the fitted net revenue model as shown in Table 2, the impact of changing climate variables on the net revenue per hectare was analyzed using the equation 5. The results of the predicted impacts from SRES models are presented in Table 4. The table shows that majority of the predicted values on net revenue changes indicate positive impact of climate change variables on net revenue per hectare by both B1 and A2 emission scenarios. The predicted values estimated from the models CCSM, MIROC, and GFDL under A2 emission scenario during 2030, and model MIROC during 2050 predict reduction of net revenue from wheat production. On the other hand, two of the B1 2030 climate scenarios predict net reduction in net revenue from wheat production, but the other three scenarios predict gain in net revenue from wheat. Similarly, only one of the B1 2050 climate scenarios predicts damages and the other four scenarios predict benefits.

The decreased net revenues ranged from 2.91 to 24.77% and increased net revenues ranged from 5.71 to 113.34% were estimated under A2 emission scenarios during 2030 and 2050 respectively. Under B1 emission scenarios, the decreased net revenues ranged from 0.36 to 4.59% and increased net revenues ranged from 1.05 to 18.58% during 2030, whereas the net revenue decreased 32.5% during 2050.

Table 4. Impact of climate change on net revenue under forecasted climate scenarios

Model	A2 Emission Scenario		B1 Emission Scenario	
	Net return change (Tk/ha)	% change	Net return change (Tk/ha)	% change
Year: 2030				
CCSM	-1133	-11.35	-36	-0.36
ECHAM	957	9.58	1159	11.61
HADCM3	1958	19.61	105	1.05
MIROC	-2473	-24.77	-458	-4.59
GFDL	-462	-4.62	1854	18.58
Year: 2050				
CCSM	2999	30.04	1108	11.1
ECHAM	570	5.71	952	9.53
HADCM3	11315	113.34	3245	32.5
MIROC	-290	-2.91	-195	-1.97
GFDL	5398	54.07	133	1.33

However, estimates depicted above are susceptible to changes based on predictions given by the global climate models. As of now, these models are predicting climate variables on a 300x300 grid scale and in this case, Bangladesh falls into one/two grids. Our field data on temperature shows significant variation of temperature and rainfall throughout Bangladesh. The impact table shown in Table 4, therefore, is unable to illustrate the real impact of climate change. It is only indicative.

6. Conclusions and Policy Implications

The study clearly provided evidence of climate sensitivity of wheat production in Bangladesh. According to the study, it is evident that profitability of wheat production will be affected due to changes in climate variables and it will affect the total production of wheat in Bangladesh.

The regression results indicate that rainfall effect is much less than temperature effect on wheat production. Furthermore, it has shown that monthly variations of climate variables are more important than an annual average changes in the climate variable. More importantly, December, January and February temperature do not have same effect. The marginal analysis shows that a marginal change in temperature during January and February reduces the net revenue and a marginal change in temperature during December increases the net revenue. Increasing rainfall during December and January also increases the net revenue of wheat per hectare. Marginal impact of February rainfall is found to be very negligible.

Under this situation, it is important to use a downscaled global circulation model to find more robust estimates of future climate variables by districts of Bangladesh and this will provide a better picture of impact of climate change. Given these limitations, the impacts of climate change on net revenue on per hectare of wheat production under forecasted climate scenarios reveal that warming generally would reduce wheat production in Bangladesh but the effect depends on the seasonal distribution and magnitude of the warming.

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Appendix Table 1: Forecasted climate changes and emission scenario for winter season

Model	**A2 Emission scenario**		**B1 Emission scenario**	
	Temperature (°C)	Rainfall (%)	Temperature (°C)	Rainfall (%)
Year: 2030				
CCSM	1.63	-12.4	1.45	11.3
ECHAM	0.43	50.1	0.19	43.6
HADCM3	1.87	27.4	1.42	15.0
MIROC	0.99	-20.6	0.99	14.1
GFDL	2.06	-19.7	1.82	29.1
Year: 2050				
CCSM	2.32	9.4	1.54	31.1
ECHAM	1.29	109.8	0.85	76.6
HADCM3	2.97	46.7	2.10	33.5
MIROC	1.63	0.4	1.43	9.1
GFDL	2.99	-18.2	2.60	-39.1

Source: Nakićenović and Swart, 2000; Mendelsohn *et al*., 2009