Climate Effect on Supply and Market Price Stability of Rice in Bangladesh: Assessment of Climate and Socioeconomic Scenarios

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This study aimed to predict stability of rice supply and market price in facing food security challenges. It develops supply and demand model to predict with scenarios of AR5 of the IPCC. Fluctuation of modern and local varieties yield during Aman and Boro seasons is higher in RCP6.0 compared to RCP8.5. Volatility of consumption and price is found in RCP6.0 and SSP2 as well as RCP8.5 and SSP3, but price and consumption is relatively stable in RCP8.5 and SSP3. The simulation result suggests that developing temperature-resilient Aman cultivar and ensuring irrigation facilities in the Boro season are necessary in future.

Key words: market price stability, rice, Bangladesh

1. Introduction

Even though Bangladesh has become marginally self-sufficient through steady progress in domestic rice production and broken its vicious circle of food insecurity, it remains a net rice importer (Kumar et al., 2012).

Rapid growth of economic activities in Asia results to Green House Gas (GHG) emission (mainly CO₂ emission) as projected to exceed 60 percent of global total emission by 2100. Subsequently emission increases the temperature, shapes strength and timing of monsoon, speeds up snow melt, and shortens winter (Masui et al., 2011). Increased CO₂ is expected to have positive effects on crop yield, however, the overall results of GHG concentration are detrimental, particularly in the tropics, where world’s poor tend to live (Mackill et al., 2010). Despite technological progress in crop productivity, rising global temperatures affects the stability of crop yields and market prices (Master et al., 2010). Instability of production is a major factor in the variation in food prices in Bangladesh (Talukder, 2005).

Bangladesh, with 160 million people, is considered an overpopulated and low-income (US$958 per capita) country in South Asia. About 31.5% of its people live below the poverty line and are vulnerable to food price hikes (World Bank, 2015). Sharp increases in rice prices lower the real income and aggravate the instability of food security of poor people because they spend a large part of their income on food (Talukder, 2005; Mondol et al., 2010). Therefore, future rice production and price stability is very important for food security in Bangladesh.

Kumar et al. (2012) predicted future supply of rice in Bangladesh using average scenarios of growth of acreage, yield, and investment in agriculture. None predicts the effects of climate change on the stability of supply and market prices in the future. With growing populations and climate change, planning for stable supply and market prices to meet future food demand requires forecasting climate effects on variations of supply and market prices. The present study develops a supply and demand model that predicts the effects of climate change on the stability of supply and market prices of rice using climate and socioeconomic scenarios of the 5th Assessment Report (AR5) of the Intergovernmental Panel on Climate Change (IPCC).

2. Model

The rice-growing seasons in Bangladesh are distinctive: Aus season is from March to late July, Aman from May to late-December, and Boro from November to late-May.

To predict the stability of supply and market price of rice under climate change, rice yield, acreage, stock change, and demand functions are developed. Furuya and Meyer (2008) used a supply and demand model to predict production and market prices in Cambodia. The variables used for supply estimation are production, imports, stock change, and indirect demand. Yield and acreage are combined to obtain production. The variables used for demand estimation are population, Gross Domestic Product (GDP), and market prices. The variables such as change in retail price and rice production are incorporated in the stock change function

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while import function includes world price and current year production. Considering the climate as one of the major determinants, yield function is built incorporating climatic variables (rainfall, temperature, and solar radiation) and time trends, as used for technological progress (improved cultivars, all kind of machineries and fertilizers). Rice yield in Bangladesh has a long term increasing trend, which is characterized by the constant spreading of advanced technologies and support by both government and NGOs. Variation in yield caused by climate factors is substantially higher in Bangladesh than variation in yield (minimal) which is attributed to farmers’ decision. In addition, the purpose of this manuscript is to focus on impact of climate on long term outlook of rice supply and price stability. That is why we do not incorporate farmers’ adjustment and expectation in yield function. The area function is constructed based on a joint assumption of partial adjustment and adaptive expectations (Nerlove, 1958) to predict farmers’ responses to supply prices and climate factors. However, separate yield and acreage functions are developed to capture inter-seasonal dispersion of yields and areas because rice yields and areas differ across varieties and seasons (Kumar et al., 2012).

Monthly average climate variables are categorized according to seasonal periods. The inclusion of dummy variables in the area and other functions facilitates explanatory power of model and climate related extreme events, such as cyclone, flood, and drought year. Explanatory variables in the supply and demand model are categorized as endogenous (squares in Figure 1) and exogenous (circles in Figure 1). The estimated functions including endogenous and predetermined exogenous variables are detailed as follows.

**Yield functions**

\[
Y_{Rt_v} = \alpha_{vR} T + b_{0R} Z_{int}
\]

where \(Y_{Rt_v}\) is the paddy yield of varieties, \(v = 1 \text{ and } 2\) (modern and local) in seasons \(i = 1, 2, \text{ and } 3\) (Aus, Aman, and Bora). \(T\) is the time trend and \(Z_{int}\) represents seasonal climatic variables, temperature (\(T_{mp}\)), rainfall (\(R_f\)), and solar radiation (\(S_r\)) in months \(m\) in year \(t\). \(\alpha_{vR}, b_{0R}\) and \(b_{0R2}\) are parameters estimated as statistically significant.

**Area functions**

\[
A_{Rt_v} = a_{vAR} + b_{0AR} A_{R(t-1)} + b_{0AR3} R_{f(m(t-1))}
\]

where \(A_{Rt_v}\) is the harvested area and \(A_{R(t-1)}\) is the lagged area. \(F_{P,1}\) is the lagged farm price deflated by lagged GDP deflator \(GDP_{D(t)}\) and \(R_{f(m(t-1))}\) is the lagged of seasonal rainfall in months \(m\). \(a_{vAR}, b_{0AR1}, b_{0AR2}\) and \(b_{0AR3}\) are estimated parameters.

**Paddy and milled rice identity**

To obtain total production of milled rice, area and yield were combined and multiplied by a standard ratio as follows:

\[
\sum_{v,i} Q_{PR} = \sum_{i,v} A_{R} * Y_{R_t_v}
\]

\[
\sum_{i,v} Q_{R} = 0.67 * \sum_{i,v} Q_{PR}
\]

where total production is \(Q_{PRt_v}\) and milled rice \(Q_{Rt_v}\) is determined by a standard conversion ratio of 0.67.

**Import function**

Encountering difficulty and uncertainty in import and international trade along with the famine in the past, Bangladesh has adopted self-sufficiency policy for food and as such utilized the green revolution technologies including huge investment in agriculture. Consequently,
higher gains in rice production enable Bangladesh enough to reduce its dependency on import and food aid. Even though Bangladesh has remarkably progressed in the rice production among the major rice producing countries, Bangladesh rather imports rice as domestic production is regarded as inadequate to meet the emergency shortfall and price hikes. Historically, import has constituted barely a small share of national rice supplies. (Kumar et al., 2012; Talukder, 2005; Dorsh and Rashid, 2012). However, Bangladesh does likely not participate in world rice trade very much. Therefore, supply and demand of Bangladesh does indeed not affect world price of rice (WPR), which is used as exogenous factor in the import model as follows:

\[ QSR_t = a_{QSR} + b_{QSR} \cdot \text{WPR}_t + c_{QSR} \cdot \text{FP}_t \]  

Imports (IMPR) are modeled by domestic production (QRo) and world price (WPR) (Thailand 5% broken) over retail price (RPR) normalized by the GDP deflator GDPD, EXR is the exchange rate (BDT/US$). \( a_{IMPR}, b_{IMPR}, \) and \( b_{IMPR2} \) are estimated parameters.

**Stock change function**

\[ STC_t = a_{STC} + b_{STC1} \cdot QRo_t - b_{STC2} \cdot QRo_{t-1} \]  

Stock change is ending stock minus beginning stock. The stock change (STC) function is influenced by variation between present production (QRo) and lagged production (QRo-1) and between present realized retail price (RPR) and lagged price (RPR-1). \( a_{STC}, b_{STC1}, \) and \( b_{STC2} \) are estimated parameters.

**Net supply identity**

\[ QSR_t = QRo_t + IMPR_t - EXR_t \cdot STC_t - PROC_t - SEED_t - FEED_t - OU_t \]  

where QSR is net supply determined by adding imports (IMPR) and subtracting change in stock (STC) as well as indirect demand (export EXPt, processed PROC, seed SEED, feed FEED, and other uses OU).

**Demand function**

The demand function was developed using utility theory, as follows.

\[ QDR_t = a_{QDR} + b_{QDR1} \cdot \text{WPR}_t + b_{QDR2} \cdot \text{PPW}_t + b_{QDR3} \cdot (\text{GDPD}_t / \text{POP}_t) \]  

where per capita demand (QDR) is influenced by retail price (RPR), the wheat retail price (PPW), which is a major substitute of rice, and income (GDPD/POP) where GDPD is gross domestic product and POP is population. \( a_{QDR}, b_{QDR1}, b_{QDR2}, \) and \( b_{QDR3} \) are estimated parameters. Moreover, the projected GDP, common scenarios to all researchers, is estimated by the SSPs of IIASA. On the other hand, the share of rice in GDP is not so larger such as 5% in 2014 (BBS, 2014), thus per capita GDP is incorporated as exogenous scenarios in the demand model.

**Market equilibrium of supply and demand**

\[ QDR_t \cdot \text{POP}_t = QSR_t \]  

**Price linkage function**

The market price of rice in Bangladesh is upstream transmission.

\[ FP_t = a_{FP} + b_{FP} \cdot \text{RPR}_t \]  

\( FP_t \) is the farm gate price, which is influenced enormously by the retail price (RPR). \( a_{FP} \) and \( b_{FP} \) are statistically significant parameters to be estimated.

## 3. Data and Scenarios

Historical areas and yields are gathered from the Bangladesh Bureau of Statistics (BBS, 2014). Additional data related to farm and retail prices are collected from world rice statistics. Exports, imports, and stock change of rice are collected from the Food and Agriculture Organization (FAO) as well as GDP and GDP deflator are from World Data Bank (World Bank). Then, historical temperature, rainfall, and solar radiation are collected from the Data Distribution Centre of the IPCC. Forecast climatic variables from 2010 to 2030 is used from Model for Interdisciplinary Research on Climate (MIROC5), General Circulation Model (GCM) of the University of Tokyo, NIES (National Institute for Environmental Studies) and JAMSTEC (Japan Agency for Marine–Earth Science and Technology). Forecast GDP and population under Shared Socio–economic Pathways (SSPs) of the AR5 of the IPCC is incorporated with climate scenarios to predict food situation and price instability in the future under climate change. The IPCC AR5 has developed four Representative Concentration Pathway (RCP) scenarios defined in terms of radiative forcing and direction of change. Among the representative scenarios, two contrasting scenarios are selected: RCP6.0 is medium baseline mitigation and stabilized at 6.0 W/m² (855 ppm CO₂ eq.) and rapid economic growth in Asia while RCP8.5 is described as a
high emission pathway and radiative force stabilized at 8.5 W/m² (1,370 ppm CO₂ eq.) by 2100. In addition, each scenario has its own fluctuation of climate variables, which would cause the fluctuation of rice production in the era of climate change. Since both scenarios project high emission of GHG from Asian region, they are more suitable to represent climate change in Asian region including Bangladesh. SSP2 and SSP3 scenarios are chosen among many combinations of the SSPs of IIASA (International Institute for Applied Systems Analysis), SSP2 represents intermediate challenges in which population and GDP increase moderately. SSP3 represents high mitigation and adaptation challenges in which population growth is high and GDP growth is very low but a de-globalized region attempts to achieve food security within its region.

However, linear approximation method is used to extrapolate the GDP deflator, world price of rice and exchange rate, which are used in the forecast period. RCP and SSP scenarios are incorporated into the supply and demand model simultaneously to predict stability of market price and per capita consumption from 2010 to 2030.

4. Estimation Method
Both Ordinary Least square (OLS) and Two-Stages Least Square (2SLS) methods are attempted to estimate the parameters of the aforementioned functions. Based on the dataset from 1977 to 2009, we estimate the parameters of equation (1), (2), (5), (6), (8), and (10) using Ordinary Least Square (OLS) (see in the Table A1–A3 in the Appendix). OLS is found to perform well and the value of adjusted $R^2$ of all functions estimated with ranges from 0.75 to 0.99 is sufficiently high. In addition, the estimated model is checked for presence of auto-correlated error terms by applying Durbin–Watson (DW) d and h statistics for functions with and without lag dependent variables. DW values ranging from 1.60 to 2.50 indicates that there is no serial correlation, so the results of parameter estimates are representative enough to explain the phenomenon of the prediction model. The prediction period is extended based on the econometric analysis from 2010 to 2030. To end with, the market clearing price is obtained when difference of net supply and demand is equal to zero, and solving the model by Gauss-Seidal algorithm (Meyer et al., 2006).

5. Results and Discussion
The assumptions of the simulation are as follows: i) the estimated parameters are fixed. ii) the linear trend continues in the yield function and is flat in the area function. iii) there is an average growth of GDP deflator from 1977 to 2009 and in the exchange rate from 1995 to 2009.

Estimates and elasticities of yield and area are obtained as shown in Tables A1 and A2 in the Appendix. Stock change, import, and demand elasticity of rice obtained are shown in Table A3 in the Appendix. Simulation results on Co-efficient of Variation (CV) of yield, area, supply, price and demand are given in the Tables 1–3. CV of modern Aurs yield is 9.3% in RCP6.0, which is higher than in RCP8.5 (9.0%). CV of local Aurs yield is 9.9% in RCP8.5, which is higher than RCP6.0 (9.7%) (Table 1). Fluctuations of rainfall in July and temperature in May are observed as slightly higher in RCP6.0 compared to RCP8.5, which influences more variation of modern yield in RCP6.0. Fluctuation of rainfall in April is observed as slightly higher in RCP8.5 compared to RCP6.0, which influences more variation of local Aurs yield in RCP8.5. The climate variables in April and May are very important for Aurs crop because the crop starts panicle initiation in April and starts flowering in late May.

CV of modern Aman yield is 8.7% in RCP6.0, which is

| Table 1. CV (%) of seasonal rice yield in 2009-2030 |
|-----------------------------------------------|
| Seasonal yield | Yield variation (%) | RCP6.0 | RCP8.5 |
|                | Modern | Local | Modern | Local |
| Aus             | 9.3    | 9.7   | 9.0    | 9.9   |
| Aman            | 8.7    | 8.2   | 7.9    | 6.1   |
| Boro            | 14.7   | 13.6  | 9.5    | 10.8  |

| Table 2. CV (%) of seasonal rice area in 2009-2030 |
|-----------------------------------------------|
| Seasonal area | Area variation (%) | RCP6.0 | RCP8.5 |
|               | Modern | Local | Modern | Local |
| Aus           | 15.0   | 13.9  | 14.1   | 11.8  |
| Aman          | 2.6    | 10.2  | 1.8    | 10.9  |
| Boro          | 2.7    | 13.9  | 2.2    | 14.9  |

| Table 3. CV (%) of supply, market price and consumption in 2009-2030 |
|-----------------------------------------------|
| Variables | Historical | RCP6.0 and SSP2 | RCP6.0 and SSP3 |
| Supply of rice | 7.1 | 9.3 | 7.5 |
| Farm price | 21.5 | 25.5 | 24.2 |
| Retail price | 27.0 | 30.5 | 29.1 |
| Consumption | 4.5 | 6.5 | 4.5 |
higher than in RCP8.5 (7.9%). In addition, CV of local Aman yield in RCP6.0 (8.2%) is higher than in RCP8.5 (6.1%). The results reveals that the yields of both Aman varieties fluctuate more in RCP6.0 compared to RCP8.5 (Table 1). Fluctuations of temperature, rainfall, and solar radiation in October are observed as higher in RCP6.0 than in RCP8.5. Temperature in October is observed to be very important because the Aman crop starts flowering in this month. In addition, modern Aman varieties are relatively temperature resilient than that of local Aman but, for adaptation to future climate change, more temperature resilient varieties are necessary.

CV of both Boro yields is substantially higher in both RCP6.0 and RCP8.5 than in two other seasons, but the variation of both modern (14.7%) and local (13.6%) Boro yields is found to be much higher in RCP6.0 than the modern (9.5%) and local (10.8%) Boro yields in RCP8.5. (Table 1). The simulation shows that high fluctuation of rainfall in March in both RCP6.0 and RCP8.5 (flowering stage) influences the variation of yield in the Boro season. Therefore, ensuring irrigation facilities where there are no available water resources or no well-developed irrigation system during the flowering stage of Boro crops are very important for stable rice production in the era of climate change. Fluctuations of seasonal temperature and rainfall are found to have a significant influence on instability of rice production.

High volatilities of per capita consumption and market price are found in RCP6.0 and SSP2 as well as RCP8.5 and SSP3, fluctuation of consumption (4.5%), farm price (24.1%), and retail price (29.2%) are relatively smaller in RCP8.5 and SSP3 than those in RCP6.0 and SSP2 (6.5%, 25.5%, and 30.5%) (Table 3). Fluctuation of supply is also found to be relatively higher in RCP6.0 and SSP2 (9.3%) than that in both RCP8.5 and SSP3 (7.5%) and historical period (7.1%) (Table 3). High volatility of price negatively affects the consumption of low-income people and producer decision in the prediction period (Tables 2–3).

6. Conclusion

The results conclude that fluctuations of seasonal temperature and rainfall are found to have a significant influence on the instability of rice production in both RCP6.0 and RCP8.5. However, yield variations in the two major seasons (Aman and Boro) are higher in RCP6.0 than RCP8.5. Despite increasing volatility, variation of consumption and market price are found in all scenarios. Per capita consumption, farm price, and retail price are relatively stable in RCP8.5 and SSP3 than in RCP6.0 and SSP2.

In summary, the result reveals that the governments of Bangladesh have to implement policy for the development of temperature-resilient Aman cultivars and ensure irrigation where there are no available water resources or no well-developed irrigation facilities in Boro season.

The results further wrap up that this study update the literatures to be considered by policy makers so as to make policy for reduction climate impact on price fluctuation in the era of climate change.

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Table A2. Estimates of area functions (equation (2))

| Area | Trend | Area (t-1) | Price (t-1) | Climate variables (t-1) | AdjR2 | DW |
|------|-------|------------|-------------|-------------------------|-------|----|
| AuvM | 0.70*** | 6.6*** | -1095*** | 0.93 | 2.37 |
|      | (12.56) | (2.70) | (-5.14) | | |
|      | [0.069] | [0.10] | [-0.06] | | |
| AuvL | ** | ** | -28372 | 0.31* | 27.3** | 0.99 |
|      | (-3.25) | (1.76) | (2.18) | (2.09) | (-2.11) | 1.79 |
|      | [-0.32] | [0.32] | [0.13] | [0.03] | [0.04] | |
| AuvL | 30.13*** | 0.74*** | 51.4*** | 0.99 | 2.14 |
|      | (2.22) | (5.42) | (2.32) | (2.25) | (1.70) | |
|      | [0.24] | [0.71] | [0.18] | [0.04] | [0.02] | |

Table A3. Estimates of demand, stock change, import, and price link functions (equation (5), (6), (8), and (10))

| Equation | Constant | Variable estimate | Variable estimate | AdjR2 |
|----------|----------|------------------|------------------|-------|
| Demand (Per capita) | 229*** | -0.003*** | 0.004*** | 0.75 |
|         | (9.68) | (-4.32) | (2.82) | |
|         | [0.048] | [0.23] | [0.12] | |
| Stock change | AQ | -71.81*** | -80704*** | 0.93 |
|         | (12.18) | (-2.30) | (-4.83) | 2.03 |
|         | [1.51] | [0.05] | [4.38] | |
| Import | QB | -0.04* | -442073* | 0.60 |
|         | (4.87) | (-2.00) | (-1.96) | 2.15 |
|         | [-1.70] | [-0.86] | |
| Price linkage | 639 | 0.41*** | 0.92 | 2.08 |
|         | (1.53) | (11.45) | | |

*** and * indicates level of significance at 1, 5 and 10%