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Is Growth in Bangladesh's Rice Production Sustainable?

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The current level of per capita production of rice in Bangladesh can be sustained only through increased yields of modern rice varieties.

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Summary findings

The recent growth of foodgrain (primarily rice) production in Bangladesh has outpaced population growth largely because of the spread of green revolution technology. The transition from being labeled a "basket case" in the early 1970s to the virtual elimination of rice imports in the early 1990s is particularly remarkable considering the severe land constraint in Bangladesh. Two decades of concerted government efforts to achieve rice self-sufficiency have created both an atmosphere of optimism and concerns about whether rice self-sufficiency is sustainable.

Baffes and Gautam find that rice production grew in Bangladesh between 1973 and 1994 mainly because of the conversion of rice-growing areas from local to modern varieties. Simulations suggest that the current level of per capita production can be sustained only through increased yields from modern rice varieties.

Other factors that could affect growth in per capita rice production are population control (which is found to have significant long-term benefits) and faster conversion of remaining areas to modern varieties (which is found to have important short-run payoffs).

But population control and faster conversion to modern varieties are only complements for the most important factor: efforts to increase the yields from modern rice varieties. If policies designed to raise the overall rate of economic growth and reduce poverty succeed, it will be even more critical to focus on increasing productivity.

This paper — a product of the Commodity Policy and Analysis Unit, International Economics Department — is part of a larger effort in the department to analyze global food security issues. Copies of the paper are available free from the World Bank, 1818 H Street NW, Washington, DC 20433. Please contact Pauline Kokila, room N5-030, telephone 202-473-3716, fax 202-522-3564, Internet address pkokila@worldbank.org. October 1996. (29 pages)

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1. Introduction

The growth of foodgrain production in Bangladesh – primarily rice – has outpaced population growth largely because of the spread of green revolution technology. The transition from being labeled a "basket case" in early the 1970s to the virtual elimination of rice imports in the early 1990s is particularly remarkable considering the severe land constraint in Bangladesh. A culmination of two decades of concerted efforts by the Government towards rice self-sufficiency, this feat has simultaneously created an atmosphere of optimism and raised concerns about its sustainability.

The discussion on the sustainability of output growth in Bangladesh is topical in light of the current debate on the Earth's carrying capacity. Projections of future global food demand and production levels, although based on the same historical data, differ depending on the assumptions maintained (McCalla). For example, Mitchell and Ingco argued that if past trends in crop yields continue and population growth rates decline as projected, then improvements in the world food situation as seen in the past 30 years should continue. Brown and Kane, on the other hand, argue that several constraints are emerging to prevent past trends from continuing.

Additional research also suggests that the current, relatively comfortable food situation may not last for long and that complacency at this time is misplaced and premature (Pinstrup-Anderson and Pandya-Lorch). With limits on cultivable area, rapid population growth, stagnating yields, and potential resource degradation, the future does not appear to be promising. It is generally argued that raising yields are the key to promoting and sustaining growth in food output. In the long run, this would entail increased research to develop superior grain varieties; in the short run, it requires dissemination of accumulated knowledge, delivery of appropriate technology, and input intensification to close existing yield gaps (Anderson et al.).

The objective of this paper is to evaluate the future prospects of rice for Bangladesh under alternative strategic policy directions. The analysis serves two purposes. One is to assess the future growth prospects for Bangladesh's agriculture. The analysis is focused on rice because it is the most important crop, contributing 70% of crop GDP, and over 50% of the agricultural GDP which in turn accounts for a third of national GDP. More importantly, past growth in gross crop revenue has been due almost entirely to the growth in rice production, raising concerns whether past performance can be maintained, and if so, for how long.

The second purpose of the analysis is to use Bangladesh as a case study to contribute to the global debate on the sustainability of food output. With abundant water resources and low rice yields, Bangladesh has a relatively greater potential for expanding food production by maintaining the momentum of the green revolution than many other developing countries (Brown and Kane). Thus, with an a priori optimistic outlook, the results would be indicative of the prospects for other developing countries.

To identify the potential for further growth, the first part of the paper decomposes past growth in rice production to identify its major sources. The analysis is restricted to the growth in area and yields of rice varieties to study the impact of physical constraints on the spread of the current technology, and hence on the growth process. This framework allows identification of variables for broad policy direction. It is also complementary to micro-economic analyses; e.g., the total factor productivity approach which accounts for the contribution of inputs to output growth and duality applications that study the structural properties of production technology.

The second part of the paper is concerned with the conditions under which past growth can be sustained in the future. These conditions embody options affecting population growth, rate of conversion from traditional to modern rice varieties, rice yields, and income growth. The alternatives give profiles of per capita rice production and consumption over the next 20 years and are used to identify areas on which policy must focus to sustain growth in output. It must be emphasized that the purpose of these simulations is to qualitatively assess the effects of alternative policy thrusts on long-run outcomes. The conditions underlying each simulation are intended to reflect the necessary actions that might be needed to achieve the intended outcomes, without making any judgment on the desirability of specific policies.

2. Identifying the Sources of Growth

There are three rice cropping seasons in Bangladesh. *Aus* is a short-duration crop which is directly seeded in March-April and harvested in July-August, utilizing the pre-monsoon rain water. *Aman*, from June-August to November-January, is the monsoon crop. It grows with the flood waters and is harvested after the floods recede. Shorter duration modern *Aman* varieties have made room for short-duration non-rice crops (oilseeds and pulses) before the high-yielding dry season crop is transplanted.[1] *Boro*, from November-January to April-June, is the dry season crop. With the development of controlled (groundwater) irrigation, *Boro* modern variety rice has expanded rapidly at the expense of *Aus*.

Both local (LV) and modern (MV) varieties can be grown in all three seasons.[2] However, because of overlapping production cycles, area under the more profitable *Boro* expands at the expense of *Aus* and broadcast *Aman*. Since *Boro* rice is almost entirely irrigated, area allocated to it can also be viewed as irrigated area. Table 1 gives the 1973-75 and 1992-94 average rice production, area, and yield for the three seasons and two rice varieties.[3]

2a. Growth Decomposition

This section decomposes past growth in rice production.[4] Production in year t, Q_t, is the sum of the output of the two varieties in the three seasons:

$$Q_t = \sum_{i=1}^{2}\sum_{j=1}^{3} Q_t^{ij} \tag{1}$$

where i = MV, LV and j = *Aus*, *Aman*, and *Boro*; thus Q_t^{ij} denotes production of rice variety i in season j. Expressing Q_t^{ij} as the product of area, A_t^{ij} and yield, Y_t^{ij}, (1) can be written as:

$$Q_t = \sum_{i=1}^{2}\sum_{j=1}^{3} A_t^{ij} Y_t^{ij}. \tag{2}$$

The growth rate of total rice production, ρ, for a particular time interval ($t = m, \ldots, n$), can be expressed as the weighted sum of growth rates of each component:

$$\rho = \sum_{i=1}^{2}\sum_{j=1}^{3} w^{ij}\left(\rho_A^{ij} + \rho_y^{ij}\right), \tag{3}$$

where ρ_A^{ij} and ρ_y^{ij} denote growth rates of area and yield of variety i in season j and w^{ij} is the corresponding weight, with all weights summing to one. The weights are defined as:

$$w^{ij} = \frac{1}{n-m+1}\sum_{t=m}^{n}\frac{Q_t^{ij}}{Q_t}. \tag{4}$$

Depending on the specific objective of the decomposition, n and m can take any value within the sample range.[5]

Inserting (4) into (3) and setting $n = T$ and $m = 1$ gives the final form of decomposition:

$$\rho = \sum_{i=1}^{2}\sum_{j=1}^{3}\left(\frac{1}{T}\sum_{t=1}^{T}\frac{Q_t^{ij}}{Q_t}\right)\left(\rho_A^{ij} + \rho_y^{ij}\right). \tag{5}$$

Growth in total rice production in (5) is thus decomposed into 12 parts defined by the two varieties (MV and LV), the three seasons (*Aus*, *Aman*, and *Boro*), and the two components (area and yield). Finally, dividing both sides of (5) by ρ and multiplying them by 100 gives the decomposition in percentage terms.

2b. Estimating the Rate of Growth

Suppose that Q_t, which grows at rate ρ, is subject to stochastic shocks, u_t. That is,

$$Q_t = (1+\rho)Q_{t-1}u_t. \tag{6}$$

It is assumed that a multiplicative error, representing proportional shocks, is a more appropriate representation than an additive error, representing similar magnitudes of shock at all levels of output (Banerjee, et al.). From (6) it follows that $Q_{t-1} = (1+\rho)Q_{t-2}u_{t-1}$. Inserting Q_{t-1} into (6) gives $Q_t = (1+\rho)^2Q_{t-2}u_tu_{t-1}$, while recursive substitution yields:

$$Q_t = (1+\rho)^t Q_0 u_t u_{t-1} \cdots u_0. \tag{7}$$

Taking logarithms in (7) and setting $\mu = \ln(Q_0)$, $\beta = \ln(1+\rho)$, and $\varepsilon_t = \Sigma_t \ln(u_t)$ gives,

$$\ln(Q_t) = \mu + \beta t + \varepsilon_t. \tag{8}$$

β can be estimated with OLS and the growth rate can be calculated as $\rho = e^{\beta} - 1$, where e is the base of the natural logarithm. To what extent β is a reliable estimate, and hence reflective of the true growth rate, depends on the properties of ε_t. If ε_t is a stationary process, then ρ reflects the true average growth rate over the sample period. If, on the other hand, ε_t is nonstationary then the average growth rate as hypothesized in (6) may not exist (in the sense that the stochastic component drives Q_t in (6) rather than the deterministic one).

In the case where ε_t is $I(1)$, an alternative way to estimate the growth rate would be to take logarithms in (6), rearrange terms and substitute as before:

$$\ln(Q_t / Q_{t-1}) = \beta + \upsilon_t \tag{9}$$

where $\upsilon_t = \ln(u_t)$. The growth rate as given in (9) is simply the arithmetic mean of logarithmic changes of Q_t. Thus, for an $I(1)$ process, only the information contained in the first and last observations of the sample is useful in estimating the rate of growth.[6]

To determine if the estimated coefficients represent firm estimates of the underlying growth rates, the performance of (8) is assessed by both conventional and stationarity statistics.[7]

Further, although this single equation framework implicitly imposes the weights (4) used in the decomposition (5), the validity of this restriction can be formally tested using the nonlinear cross-equation restriction that the weighted contribution of each growth component adds up to the growth rate of total output.

3. Results

Bangladesh Bureau of Statistics (BBS) data on rice area, yield, and production for the 1973-94 period are used for the analysis.[8] The full set of regression results are reported in appendix B (table B.1). The test for the restriction on weights (4) yielded a χ^2 statistic of 0.32, far lower than its 5% critical value counterparts. Hence, the restriction that the weighted contribution of 12 components add up to the estimated total growth rate could not be rejected. The estimated growth rates, based on unrestricted OLS estimates, are reported in table 2.

Total rice production grew at an annual rate of 2.65%. Rosegrant and Pingali report that the rice output growth rate for Asia increased from 2.60% per annum during the pre-green revolution period (1958 to 1966) to 3.30% during the post-green revolution period (1966 to 1982). Thus, the 2.65% growth rate places Bangladesh well below the Asian average for the post-green revolution period. This is also consistent with evidence of low technical efficiency in the production of MV rice in Bangladesh (Sharif and Dar). Seasonal estimates show that *Boro* rice production has grown substantially (7.07%) while *Aman* production has grown at a much lower rate (1.94%) and *Aus* production has declined (-1.36%).

The growth in gross area allocated to rice production has been negligible (0.20%). That is, almost all growth in rice production has been due to increased average yields. At the seasonal level, area allocated to *Aman* rice has remained unchanged while area allocated to *Boro* rice has increased at the expense of *Aus* (at rates of 5.55% and -2.66%, respectively).

In all three seasons average yields experienced steady growth: 1.33%, 1.98%, and 1.44% for the *Aus*, *Aman*, and *Boro* season, respectively. The growth rates of all seasonal yields are below the overall growth rate of 2.44%, because a significant part of the overall yield growth has been due to the increase in *Boro* area (from 1,065 to 2,605 thousand hectares) largely at the expense of *Aus* (from 3,072 to 1,767 thousand hectares).

Distinguishing local and modern variety yields highlights some important features. Average MV yields (figure 1) remained virtually unchanged while LV yields (figure 2) grew at an average of 1.29% for the entire 1973-94 period. Disaggregating at the seasonal level, *Aus* MV yields declined at the rate of 1.92% while they remained almost unchanged for *Boro* and *Aman* (0.03% and 0.10%, respectively). Growth in LV yields for the *Aus* and *Aman* seasons was higher (1.25% and 1.29%, respectively) relative to the *Boro* LV yield growth rate (0.42%).

In the mid 1980s, the Government of Bangladesh liberalized agricultural input markets and deregulated the import of minor irrigation equipment (Hossain). This led to a rapid expansion of irrigated acreage (especially *Boro*) in the late 1980s. To allow for a structural break due to the policy reforms, growth rates were re-estimated for the two subperiods 1973-87 and 1987-94 using a kinked growth regression (see appendix A for a description of the model). As in the constant growth rate model, the hypothesis that the weighted contribution of the 12 components add up to the estimated total growth rate in each subperiod could not be rejected with a χ^2 statistic of 0.33. The growth rates of the two subperiods are reported in the middle and lower panels of table 2.

For the pre- and post-87 periods, annual growth in total rice production was estimated at 2.60% and 2.84%, respectively, while the growth in rice area was estimated at 0.47% and -0.81%, respectively. Annual MV yields in the pre-87 period experienced a decline of 0.41%, while they increased by 1.42% in the post-87 period. Overall, the results confirm a structural change in MV yields but not in LV yields. The -0.41% growth rate of MV yields in the earlier period is consistent with Rosegrant and Evenson's finding that there was little total factor productivity growth in Bangladesh between 1965 and 1985.

The negative growth rate of MV yields in the pre-1987 period raises the important issue of declining yields due to resource degradation. For example, Pingali, Moya and Velasco present evidence from the Philippines and other countries indicating stagnating and declining yields in intensively cultivated irrigated rice even in experiment station fields. Pagiola presents similar evidence of declining yields using data from Bangladeshi experiment station fields.

The upper panel of table 3 reports the weighted contribution of area and yield to overall growth by seasons and varieties for the 1973-94 period. *Boro* contributed 68% to output growth; *Aman* contributed 40% while *Aus* contributed a negative 10% to overall growth. Further decomposition reveals that: MV *Aman* and MV *Boro* yield contribution was negligible to overall growth (1% and 0%, respectively) while MV *Aus* yields reduced it by 4%. On the other hand, both LV *Aus* and MV *Aman* yields made a noticeable contribution (7% and 19%). MV and LV yields together contributed about one fourth to overall growth. The major portion of growth (three fourths) was the result of conversion from LV to MV within the *Aman* season as well as from LV in the *Aus* season to MV in the *Boro* season.

The contributions by season and variety for the two subperiods present a clearer picture of the movement from LV to MV and from *Aus* to *Boro* production. The difference is the significantly greater contribution of *Boro* and *Aman* MV area and yields to overall growth in the post-87 period, while MV *Aman* yields declined in the pre-87 period. It is evident from the lower panel of table 3 that the increase in post-87 MV output was at the expense of LV output in both *Aus* and *Aman*, primarily due to the decline in the area devoted to these crops.

To summarize: conversion from LV *Aus* and LV *Aman* to MV *Boro* contributed the most to the growth of rice production followed by conversion from LV to MV during the *Aman* season and by LV yield growth in the *Aman* season. Thus, the success of the green revolution in Bangladesh should be attributed mostly to the conversion from local to modern rice varieties and not to increase in modern variety yields. Moreover, the fact that in the last 10 years real crop GDP grew at 1.87% annually and that rice contributes about 70% to crop GDP suggests that almost the entire growth in crop GDP has been due to the conversion from local to modern rice varieties.

Wheat production in Bangladesh has followed a similar pattern. In 1973 it covered 119,000 hectares with 82% under local varieties. By 1987 the entire wheat area (540,000 hectares) was under modern varieties. Production before 1987 grew at an annual rate of 25.52%. Of this growth, area expansion accounted for 16.59% and the conversion from LV to MV and yield increases accounted for the rest. Between 1987 (when the completion of the conversion to modern varieties was completed) and 1994 wheat production grew at only 1.28% annually, with three-fourths of this growth due to area expansion and one-fourth to yield increases.

Similar findings are reported in a recent study by Byerlee and Siddiq regarding wheat production in Pakistan. They write that "The most striking trend is the slow rate of progress in yields in areas *already sown to Modern Varieties* ..." (p. 1347; emphasis in original). In particular, they found no trend over the 1967-90 period (roughly our sample period) in MV yields. The main growth in wheat production came from either conversion of rainfed to irrigated land or the switch to modern varieties. Furthermore, their evidence "... raises serious concerns about Pakistan's ability to sustain even present levels of food self-sufficiency to 2000 and beyond". (p. 1358). Faruqee also reports that MV rice yields in Pakistan have stagnated during the 1980s while they grew at only 0.20% annually during the 1970s.

In a study of rice production in the Philippines, Bouis reports that increases in proportion of area planted to MV rice was one of the major sources of growth (in addition to shifts in the fertilizer response function). Furthermore, MV rice in the Philippines has approached 90% of all rice area and can no longer be counted on as a source of growth in the future.

The decomposition findings have important policy implications for the simple reason that each of the growth components has a limited potential for expansion. For example, the land potential has already been exhausted. Thus, conversion from local to modern varieties is limited by the total area allocated to rice. When this potential is exhausted, assuming that current yield trends continue, the growth in rice production will decline significantly. Coupled with a growing population, this will imply a decline in per capita production.

4. Simulations

Based on the findings of the previous section, this section examines whether and under what conditions growth in rice production can be sustained. This is done by simulating the likely impact on per capita rice production of alternative assumptions about MV yield changes, the rate of and limits to adoption of MV technology, and population growth. Finally, to evaluate future excess supply/demand of rice, we also simulate changes in aggregate per capita demand for rice using the historical GDP growth and average income elasticity estimates.

4a. Projecting Per Capita Rice Production

Projections of per capita rice production (q_t) are based on the following relationship:

$$q_t = \sum_{i=1}^{2} A_{t-1}^{i} y_{t-1}^{i} (1 + \rho_y^{i} - \rho^{pop}) \tag{10}$$

where ρ^{pop} denotes the population growth rate while y_t is per capita yield. Ideally, one would use the growth rates and rates of conversion from LV to MV for the three seasons. However, that would complicate matters. To keep the analysis focused on main issues, simulations use aggregate levels of the key determinants of q_t in (10): MV yield growth, MV adoption, MV upper bound, and population growth. A brief discussion of each follows.

MV YIELDS: The rate of growth for the entire period in MV yields was found to be -0.03% (which for practical purposes is viewed as zero). Accounting for the structural change, the growth of MV rice yields was -0.41% in the pre-87 period and 1.42% in the post-1987 period. These provide 3 potential MV yield growth paths for the future. To these is added a relatively more optimistic scenario whereby Bangladesh is expected to increase its MV yields from the current level of 2.41 metric tons per hectare (MTH) to 3.50 MTH by the end of the 20-year period under consideration, matching the current performance of other Asian countries. This would entail an MV growth rate of 2.00%. Coincidentally, the projected 2.00% growth in MV yields is also the actual growth rate between 1987-91, reflecting the fact that although this rate might appear to be optimistic, it is not an unrealistic objective. Thus, the four assumptions regarding potential MV yield growth rates are: *(i)* -0.41%, *(ii)* 0.00%, *(iii)* 1.42%, and *(iv)* 2.00%.

MV ADOPTION: Between 1973 and 1994, the proportion of rice area allocated to MV grew from 11 to 50% reflecting a rate of growth of 7.61% (figure 3). Under this historical rate of conversion, in less than 8 years 90% of rice area will be under modern varieties. However, as the conversion is closely associated with irrigation expansion, which is becoming progressively more costly, it is unlikely that the historical rate of conversion can be maintained. Accordingly, the two rates of conversion from LV to MV considered are 3% and 5%. These may be viewed as (relatively) pessimistic and optimistic forecasts, although both are less than the historical trend.

MV UPPER BOUND & TOTAL RICE AREA: A third important consideration is the upper bound to the spread of MV technology. This is determined by the total area allocated to rice and limits on the maximum attainable MV intensity. The gross area allocated to rice has remained virtually constant over the past two decades. The agro-ecological circumstances of Bangladesh are a major constraint to further increase the rice cropping intensity, which at 182% is already among the highest in the world. Short duration varieties are already being used in the mid to higher elevations. In the lower elevations, over a third of the area is prone to annual flooding, limiting the potential for increasing the cropping intensity. For simulation purposes it is assumed that gross area allocated to rice in the future will remain constant at the 1992-94 average of 10,135 thousand hectares. Given this, two limits to the expansion of MV intensity are considered: 65% and 80% of rice area. To a limited extent, the 65/80% assumptions implicitly incorporates minor increases in gross rice area.

POPULATION GROWTH: The last parameter considered is population growth (an important policy variable). Two population growth rates are assumed: *(i)* a fixed rate of 2.05%, which was the 1980-90 inter-census growth rate, and *(ii)* a declining schedule which assumes an aggressive but attainable population policy aiming at 1.79% growth from 1996 to 2000, 1.59% from 2011 to 2005, 1.36% from 2006 to 2010, and 1.16% from 2011 to 2014 (Bos et al.). This schedule is consistent with an average annual growth of 1.49%. The first assumption represents the more pessimistic outlook (reflecting recent trends), while the latter is more optimistic.

The four MV yield assumptions, along with the assumptions corresponding to 3/5% MV adoption rate, 65/80% MV ceiling, and 2.05/1.49% population growth, give a total of 32 per capita rice production profiles, as depicted in figures 5 through 12. To put these graphs in perspective, figure 4 presents the 1973-94 trend in per capita rice production.

4b. Projecting Per Capita Rice Demand

To assess the rice imbalance associated with each production scenario, per capita rice demand is also projected. Using a semi-log specification, per capita demand at period t (denoted d_t) is projected as:

$$d_t = d_{t-1}[1+(\rho^{GDP} - \rho^{pop})\eta] \qquad (11)$$

where ρ^{GDP} is the GDP growth rate and η is the income elasticity of the demand for rice.

The GDP growth rate over the last two decades has been 4.34%.[9] The income elasticity of rice is set to 0.30. With a zero rice imbalance in the base period (consistent with token net exports in 1994), per capita demand is set at 158 kg (the 1992-94 average per capita rice production). With these parameters, two demand profiles corresponding to fixed and declining population growth are obtained. They are also depicted in figures 5 through 12.[10]

It is clear from (11) that besides population growth, GDP growth and the income elasticity of rice will affect demand projections. We assess the sensitivity of the results to a change in GDP growth rate (by raising it to 5.00%) and in the rice income elasticity of demand (by raising it to 0.40). The various production and demand scenarios outlined above allow us to evaluate the rice imbalance that is likely to emerge in the medium and long terms.

4c. Simulation Results

The simulation results in figures 5 through 12 are summarized in table 4, which gives the projected rice surplus/deficit as a percentage of per capita demand. In particular, the top two panels present surplus/deficit per capita under the assumption that demand per capita remains constant at the average 1992-94 level. In other words, it gives the change in production per capita (PPC) over the simulation period.[11] The lower two panels in table 4 present surplus/deficit per capita (SPC) under the assumption that per capita demand changes according to (11). The results presented are for years 2004 and 2014, reflecting medium and long run outcomes.[12]

The first general result is that of population control. In the medium run (i.e., 10 years), an aggressive population policy has a marginal beneficial impact on both PPC (ranging from 2 to 3%) and SPC (from 1 to 2%). The long-run impact is significantly greater, ranging from 7 to 14 for PPC and from 4 to 7% for SPC, depending on the various yield and MV intensity scenarios. Thus, from a policy perspective, population control has substantial long run pay-offs.

The second noticeable result is the impact of the speed at which MV intensity proceeds. In the long run, both paths result in the same levels of PPC/SPC for corresponding yield and population growth scenarios – this is expected since the maximum attainable intensities of 65% and 80% are reached well within the 20-year time horizon considered here.[13] Even in the medium run, identical results are obtained for the 65% MV ceiling case, which is reached in less than 10 years under both rates of adoption. The benefits of a faster rate of adoption for this case are limited to the short run (i.e., over the next 5 years or so). Raising the MV ceiling 80%, produces a significant difference in the profile of the two paths to intensity over the medium run. The accelerated path creates surplus for both demand scenarios that are 6 to 9% higher than the slower path, depending on the assumptions regarding other parameters. These short to medium run gains offer an opportunity for initiating a structural change in agriculture. The surplus under the more optimistic scenarios could be mobilized either for growth in the nonagricultural sector or to set the stage for diversification into nonrice crops. In short, increasing MV production could open a valuable window of opportunity for agricultural development.

The impact of changes in MV yields is highly significant in both the medium and long runs. As expected, assumption *(i)* on yield changes, which reflects resource degradation, has a large negative impact on both PPC and SPC, irrespective of the assumptions regarding other parameters. The magnitudes, even in the medium run, highlight the importance of addressing emerging natural resource management issues promptly or even preemptively.

Assumption *(ii)*, which reflects the zero MV yield growth, also leads to substantial declines in PPC and SPC in the long run. Even for the medium run, PPC is marginally positive only in the most optimistic case with 80% MV ceiling, accelerated MV adoption, and aggressive population control; in all other cases, it is nonpositive. Rice surplus is consistently negative, and quite substantially so, in all cases in the medium run. These results point to the high cost of maintaining status quo with respect to yield changes, irrespective of the value of other parameters. They indicate that other policies are unlikely to compensate for stagnating yields.

The MV yield growth assumption *(iii)*, which reflects the post-liberalization performance, does better in terms of production per capita, but does not offer much promise in terms of generating a surplus. In the long run, PPC is higher in all cases except that of lower MV ceiling and higher population growth. In the most optimistic case (i.e., higher ceiling and lower population growth) it is significantly higher. The corresponding performance of SPC is not as good; it is marginally lower than the current level even in the most optimistic case and gets worse with increasing pessimism about other parameters. In the medium run, PPC is higher in all cases, but SPC is positive only with higher ceiling and adoption rate scenarios.

The MV yield growth assumption *(iv)* is the most optimistic. However, as noted earlier, it is not overly ambitious since the MV yield growth rate of 2% was achieved between 1987 and 1991, the years immediately following the deregulation of agricultural input markets in Bangladesh. Not surprisingly, this assumption provides the best results under both demand profiles. PPC is positive under all parametric assumptions, with the magnitude increasing considerably for the more optimistic cases. SPC is also positive for all cases in the medium run, although only marginally with the slower adoption rate and lower adoption ceiling. In the long run, SPC is positive only for the higher MV adoption ceiling, with population control also making a significant contribution.

From a policy perspective, it is important to note the relative impacts of different parameters. To keep the discussion focused, consider the SPC associated with yield growth assumption *(iv)* for the 80% ceiling case. An aggressive population control policy increases SPC by 2% in the medium run and by 7% in the long run; increasing the rate of MV adoption raises it by 9% in the medium run, although it does not matter in the long run. The effect of increasing MV yield growth rate from 1.42 to 2.00% raises SPC by 5% in the medium run, but raises it by 11% in the long run. Similarly, the increase in SPC relative to the outcome corresponding to yield growth assumption *(ii)* is 18% in the medium run and 33% in the long run.[14]

These results highlight that it is imperative to focus on yields if PPC and SPC are to be sustained in the long run. In addition, population control has long run benefits. In the short run, in addition to increasing yields, accelerating MV adoption will be the key to further growth.

The discussion has so far concentrated on the assumptions affecting production growth. On the demand side, the projections were made under two assumptions: *(a)* with constant per capita demand, and *(b)* with per capita demand changing in response to GDP growth at the historical rate of 4.34% and an aggregate income elasticity for rice of 0.30. However, if

Bangladesh is successful in meeting the main objectives of its development policy, i.e., accelerating growth and poverty alleviation, these assumptions may not remain valid. Therefore, we simulated the likely impacts of the success of these policies on the SPC.

Raising GDP growth rate from 4.34 to 5.00% raises demand per capita and reduces the surplus. Thus, in the long run, SPC is positive only for the most optimistic scenario of MV yield growth (assumption *(iv)*), accelerated MV adoption, aggressive population control and 80% MV adoption ceiling; the magnitude of change, however, is reduced by half. In the medium run, the SPC is reduced by 2% in all cases, with the rankings of different cases remaining as in table 4.

The impact of structural poverty reduction policies (e.g., growth with redistribution or other pro-poor growth interventions) is summarily captured as an increase in the average aggregate income elasticity from 0.30 to 0.40 since lower income groups have a higher income elasticity of demand. The impact is to reduce SPC, with magnitudes of change being coincidentally similar to the case of increasing GDP growth from 4.34% to 5.00%.

To maintain or increase output, both these simulations on the demand side underscore the earlier conclusion that attention has to focus on raising yields. They also have important implications for food self-sufficiency as an indicator of economic performance. The results suggest that achieving self-sufficiency can be very misleading when considered in isolation from other indicators such as production growth. This is because a slow-down in the rate of growth of GDP, or a more unequal distribution of income, will tend to produce a higher surplus (or lower deficit). Thus, while the economic performance may be deteriorating and/or poverty increasing (as indicated by a worsening income distribution), it might appear as if the country were doing well as measured in terms of achieving self-sufficiency, a cherished goal in a number of developing countries.[15]

Finally, one methodological point related to the global food security debate is in order. As mentioned in the introduction, studies have reached substantially different conclusions despite using the same historical evidence. The results obtained here show that holding all other parameters constant, varying the period over which the growth rate of modern variety yields is estimated gives dramatically different outcomes. For example, for the population growth of 1.49% and MV ceiling of 80% in the changing demand case, MV yield growth based on the 1973-94 or 1987-94 periods (0.00 and 1.42%) give a deficit of 32% or a surplus of 10%, respectively, 20 years hence. Or, relative to the 1992-94 average production of 10.9 million metric tons (MMT), Bangladesh could face a deficit of 3.5 MMT or a surplus of 1.1 MMT, depending on which estimate is used. Clearly, the former would qualify as a Malthusian outcome while the latter would be a no problem outcome.

5. Conclusions

With the area allocated to rice remaining virtually unchanged during the 20-year period examined, almost the entire growth in rice production in Bangladesh can be attributed to rising average yields. Further decomposition, however, revealed that almost two thirds of the growth was attributable to the conversion from local to modern varieties rather than to increases in varietal yields. Before the 1987 deregulation of the minor irrigation equipment sector, modern variety yields experienced an annual decline of 0.47%, raising concerns of resource degradation.

Simulation results reveal significant insights on the prospects for further growth in rice output in Bangladesh. Population control has long-run benefits, and speeding up the conversion from LV to MV could yield valuable surplus in the short to medium run. However, in the long run, these measures by themselves are unlikely to be able to compensate for a failure to raise yields. Further, if policies designed to raise the overall rate of economic growth and reduce poverty succeed, it will be even more critical to focus on yields. The results also suggest that focusing on self-sufficiency as a primary policy objective, in isolation from other indicators such as economic growth and income distribution, can be very misleading.

These findings have important implications for the global debate on the future food supply-demand imbalance. As an optimistic case for further gains from the current green revolution technology, the outlook for Bangladesh is quite revealing. There is clearly no alternative to increasing yields. This would entail a fuller exploitation of available technology by closing the existing yield gaps, increased research efforts to develop varieties with higher yield potentials, and additional research on the likely impact of current practices to pre-empt declining yields due to resource degradation.

Endnotes

1 Farmers have little choice for diverting *Aman* land to other crops because of high soil moisture and poor drainage.

2 As Byerlee recently noted, in many developing countries there has been a continuous release of MVs since the 1980s. Between 1967 and 1994 a total of 36 modern varieties have been released in Bangladesh – two by the International Rice Research Institute (1967 and 1969) and 34 by the Bangladesh Rice Research Institute (1970 through 1994). At least 18 releases of the semi-dwarf and short-duration varieties have been unpopular because of lower yield potentials as well as agro-ecological constraints (Hossain). The most popular variety, BR-11 (introduced in 1980), currently covers over 73% of total rice area. Almost all the remaining popular varieties have yields similar to BR-11. Therefore, to avoid unnecessary complexity, a homogenous modern variety (MV) is assumed.

3 Years refer to crop years; for example, 1973 refers to the crop year 1972-73.

4 Alauddin and Tisdell (1986) review the growth decomposition literature and evaluate alternative methods.

5 For example, for a 2-period change, the weights are calculated as $w^{ij} = (1/2)[Q_t^{ij}/Q_t + Q_{t-1}^{ij}/Q_{t-1}]$.

6 To see this, consider a 3-period case where growth rates between periods 1 and 2 and between 2 and 3 are given by $\ln(Q_2/Q_1)$ and $\ln(Q_3/Q_2)$, respectively. The average growth rate is $(1/2)[\ln(Q_3/Q_2)+\ln(Q_2/Q_1)]$ or $(1/2)\ln(Q_3/Q_2)$, hence not using information on Q_2.

7 The augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) stationarity statistics were calculated for the disturbance term of each trend regression. They are reported in appendix B.

8 Pray in examining the quality of the Bangladeshi agricultural statistics, argued that the statistics – especially in the pre-independence period and a few years after independence – are not accurate. Given the desire to include as much information as possible in the post-green revolution period but at the same time retain an acceptable quality of data, the analysis starts in 1973, although complete rice data are available since 1969. In addition to the quality problems, there is some evidence that official rice statistics may contain artificial noise, a result of attempts by the Ministry of Food to attract foreign aid. Boyce (1987) and Alauddin and Tisdell (1987) discuss the data quality issue.

9 The GDP trend regression coefficient was 0.0425 (t-value = 32.35, R^2 = 0.98, ADF =-3.99, PP = -4.01). The income elasticity of rice using the 1988 Household Expenditure Survey (BBS, 1991) was estimated to be 0.40. Ahmed and Goletti have used elasticities equal to 0.40 and 0.35. However, local researchers recommend that a lower figure would be a more realistic and updated estimate.

10 It should be noted that prices are assumed to remain constant at the current level. With the current domestic price of rice between import and export parity levels, projecting domestic price changes would, in effect, reflect assumptions on world price movements which, although important scenarios, are beyond the scope of the present study.

11 The assumption of constant per capita demand is equivalent to assuming that GDP and population growth rates are identical, income elasticity of demand is zero, or a combination of the two factors.

12 Rice imbalance is calculated as $q_t - d_0$ for constant and $q_t - d_t$ for variable demand. The percentage changes are calculated as: $PPC_t = 100*(q_t - d_0)/d_0$ and $SPC_t = 100*(q_t - d_t)/d_t$, which are the figures reported in table 4.

13 For the slow (3%) and accelerated (5%) rate of MV adoption, the 65% ceiling is reached in 9 and 6 years, while the 80% ceiling is reached in 16 and 10 years.

14 At the suggestion of one reviewer, we considered the possibility of increasing cropping intensity, effectively increasing total area. Simulation results indicate that holding MV yields at the current levels (scenario *ii*) and population following the low growth path, the cropping intensity would have to increase to 2 to maintain a zero rice imbalance in the year 2014 in the changing demand case (compared to the projected deficit of 23% if cropping intensity remained at the current level of 1.82). However, as noted earlier, the potential for inceasing cropping intensity significantly beyond the current levels is limited.

15 Ahmed presents a similar argument by attributing the recent state of rice self-sufficiency in Bangladesh in part to a worsening income distribution (in addition to urbanization and cross-price effects).

Table 1. Rice Summary Statistics: Production, Area, and Yields

	Total Rice			*Modern Varieties*			*Local Varieties*		
	Output	*Area*	*Yield*	*Output*	*Area*	*Yield*	*Output*	*Area*	*Yield*
1973-75 Average									
Annual	10,920	9,766	1.12	3,277	1,351	2.41	7,683	8,414	0.91
Aus	2,644	3,072	0.86	414	160	2.61	2,230	2,912	0.77
Aman	6,095	5,628	1.08	1,336	629	2.09	4,759	5,000	0.95
Boro	2,180	1,065	2.05	1,527	562	2.75	654	503	1.30
1992-94 Average									
Annual	18,213	10,135	1.80	11,973	4,969	2.41	6,239	5,166	1.21
Aus	2,035	1,767	1.15	733	396	1.85	1,301	1,371	0.95
Aman	9,456	5,763	1.64	4,898	2,233	2.19	4,558	3,530	1.29
Boro	6,722	2,605	2.58	6,342	2,340	2.71	380	265	1.43

NOTES: Area and output are in thousands of hectares and thousands of metric tons; yields are in MTH. Averages may not add up exactly because of rounding. Reported yields are period averages of production divided by area. **SOURCE:** Calculated by the authors. Original data from Bangladesh Bureau of Statistics.

Table 2. Growth Rates

	Total Rice			*Modern Varieties*			*Local Varieties*		
	Output	*Area*	*Yield*	*Output*	*Area*	*Yield*	*Output*	*Area*	*Yield*
1973 to 1994									
Annual	2.65	0.20	2.44	7.80	7.83	-0.03	-1.28	-2.54	1.28
Aus	-1.36	-2.66	1.33	1.97	3.97	-1.92	-2.28	-3.49	1.25
Aman	1.94	-0.04	1.98	8.58	8.55	0.03	-0.74	-2.00	1.29
Boro	7.07	5.55	1.43	9.06	8.95	0.10	-3.03	-3.43	0.42
1973 to 1987									
Annual	2.60	0.47*	2.12*	7.42	7.86	-0.41*	-0.13*	-1.41*	1.30
Aus	0.59*	-0.72*	1.32	5.17*	8.06*	-2.67*	-0.42*	-1.57*	1.17
Aman	1.73	0.04	1.69	7.15	7.68	-0.49	0.28*	-1.13*	1.43
Boro	6.57	4.86	1.63	8.86	8.86	-0.00	-2.75	-3.49	0.76
1987 to 1994									
Annual	2.84	-0.81*	3.68*	9.24	7.71	1.42*	-5.50*	-6.66*	1.24
Aus	-8.40*	-9.63*	1.36	-9.26*	-10.13*	0.97*	-9.00*	-10.38*	1.54
Aman	2.72	-0.35	3.08	14.11	11.86	2.01	-4.51*	-5.23*	0.75
Boro	8.98	8.22	0.71	9.82	9.29	0.48	-4.05	-3.23	-0.86

NOTES: Growth rates have been estimated using regression (8) – tables B1 and B2 (appendix B) report the full set of results. Asterisks in the lower two panels denote rejection of the hypothesis of equality of the pre- and post-1987 period growth rates (5% level). SOURCE: Calculated by the authors. Original data from Bangladesh Bureau of Statistics.

Table 3. Growth Decomposition

	Total Rice			*Modern Varieties*			*Local Varieties*		
	Output	*Area*	*Yield*	*Output*	*Area*	*Yield*	*Output*	*Area*	*Yield*
1973 to 1994									
Annual	**100**	8	92	126	126	0	-28	-56	28
Aus	-10	-20	10	4	**8**	**-4**	-13	**-19**	**7**
Aman	40	-1	41	50	**50**	**0**	-11	**-29**	**19**
Boro	68	53	14	74	**75**	**1**	-4	**-5**	**1**
1973 to 1987									
Annual	**100**	18	82	99	105	-5	-3	-35	33
Aus	5	-6	12	12	**19**	**-6**	-3	**-10**	**8**
Aman	37	1	36	33	**36**	**-2**	5	**-19**	**24**
Boro	53	39	13	55	**55**	**0**	-5	**-6**	**1**
1987 to 1994									
Annual	**100**	-29	130	180	151	28	-86	-105	19
Aus	-46	-53	7	-16	**-17**	**2**	-34	**-40**	**6**
Aman	50	-6	56	103	**86**	**15**	-49	**-57**	**8**
Boro	103	94	8	104	**98**	**5**	-4	**-3**	**-1**

NOTES: Figures represent the weighted contributions to overall growth, expressed as percentages. Bold-face figures represent the 12 components of the overall growth rate – text equation (5). **SOURCE:** Calculated by the authors. Original data from Bangladesh Bureau of Statistics.

Table 4. Projected Rice Surplus(+)/Deficit(-) as a Percentage of Demand

	Percentage change in 2004				*Percentage change in 2014*			
	Population Growth: 2.05%		*Population Growth: 1.49%*		*Population Growth: 2.05%*		*Population Growth: 1.49%*	
	65%	*80%*	*65%*	*80%*	*65%*	*80%*	*65%*	*80%*
Constant Demand (PPC) – Low MV Adoption Rate (3%)								
i (-0.41%)	-10	-9	-8	-7	-27	-23	-19	-15
ii (0.00%)	-7	-6	-5	-4	-22	-17	-14	-9
iii (1.42%)	3	5	6	8	-3	6	7	17
iv (2.00%)	8	10	11	13	6	18	17	29
Constant Demand (PPC) – Accelerated MV Adoption Rate (5%)								
i (-0.41%)	-10	-4	-8	-1	-27	-23	-19	-15
ii (0.00%)	-7	0	-5	3	-22	-17	-14	-9
iii (1.42%)	3	13	6	16	-3	6	7	17
iv (2.00%)	8	19	11	22	6	18	17	29
Changing Demand (SPC) – Low MV Adoption Rate (3%)								
i (-0.41%)	-16	-15	-15	-14	-36	-33	-32	-28
ii (0.00%)	-14	-13	-12	-11	-32	-28	-27	-23
iii (1.42%)	-3	-2	-2	0	-15	-7	-10	-1
iv (2.00%)	1	3	3	4	-7	3	-1	10
Changing Demand (SPC) – Accelerated MV Adoption Rate (5%)								
i (-0.41%)	-16	-10	-15	-8	-36	-33	-32	-28
ii (0.00%)	-14	-7	-12	-5	-32	-28	-27	-23
iii (1.42%)	-3	6	-2	8	-15	-7	-10	-1
iv (2.00%)	1	11	3	13	-7	3	-1	10

NOTES: 65% and 80% refer to the MV ceiling. The figures in parentheses of the first column represent the four scenarios for MV yields. **SOURCE:** Calculated by the authors. Original data from Bangladesh Bureau of Statistics.

FIGURE 1: Modern Variety Rice Yield

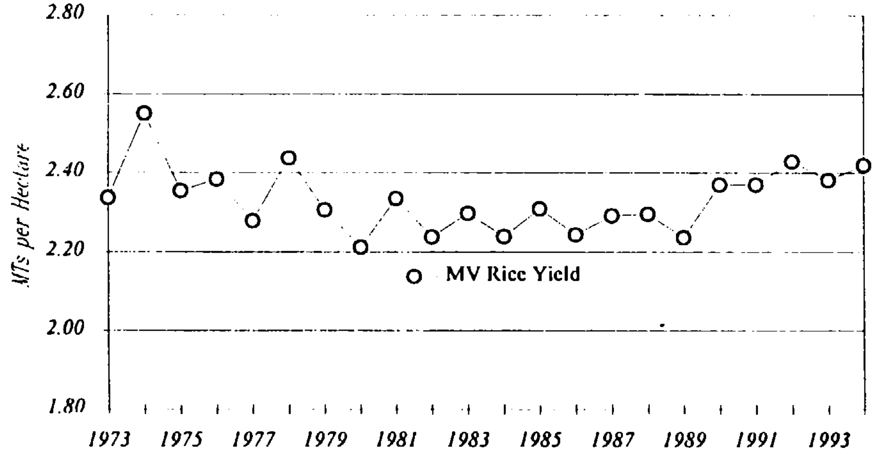


FIGURE 2: Local Variety Rice Yield

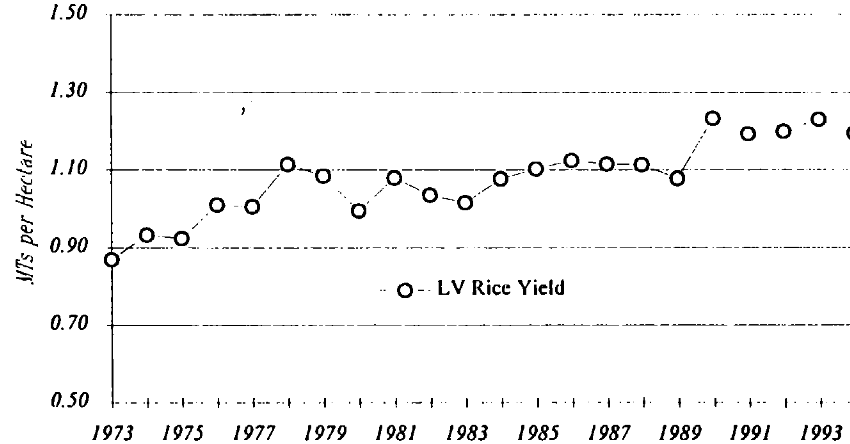


FIGURE 3: Gross Area Allocated to Rice

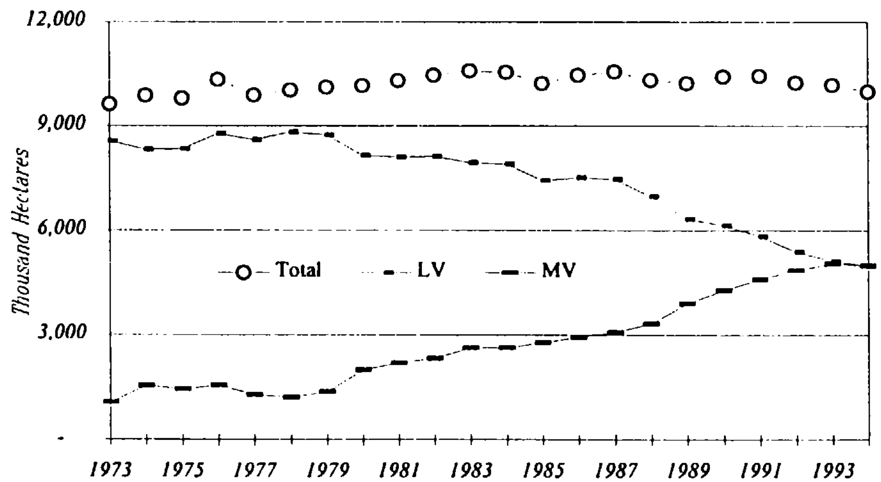


FIGURE 4: Per Capita Rice Production

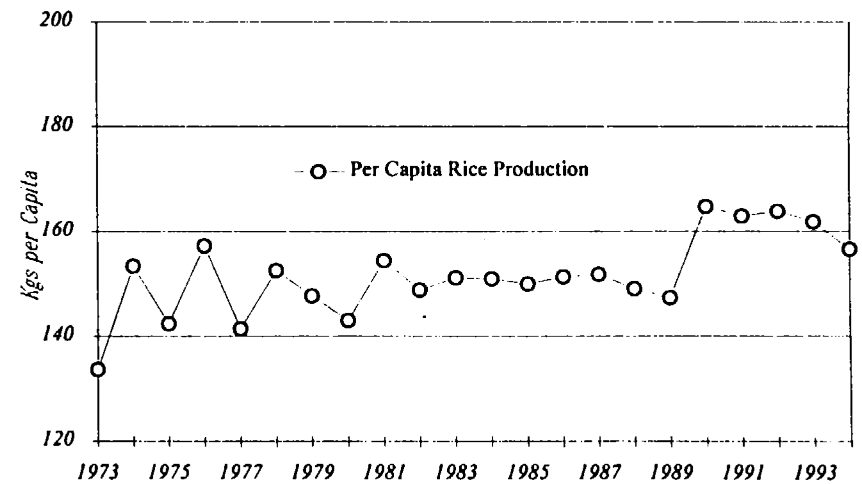


FIGURE 5: 2.05% Population Growth, 3% MV Adoption, 65% MV Ceiling

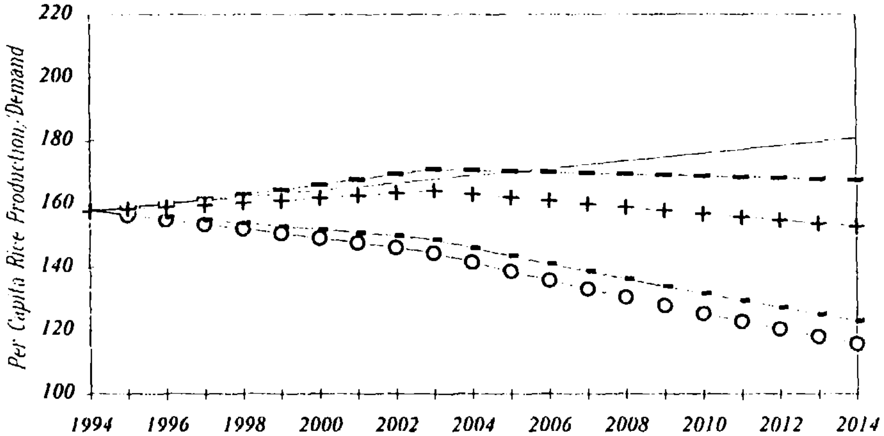


FIGURE 6: 2.05% Population Growth, 5% MV Adoption, 65% MV Ceiling

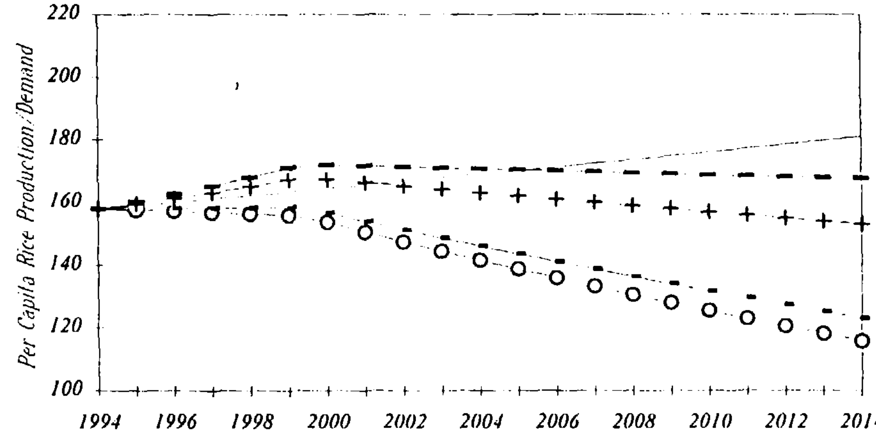


FIGURE 7: 1.49% Population Growth, 3% MV Adoption, 65% MV Ceiling

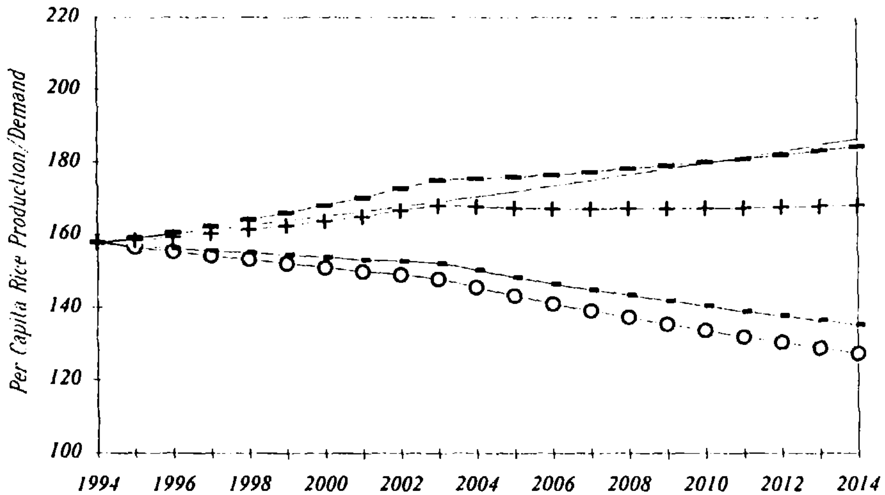
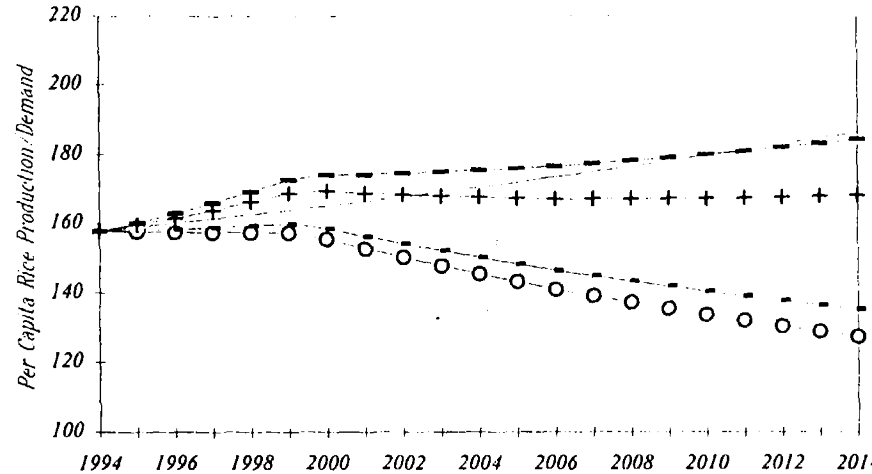


FIGURE 8: 1.49% Population Growth, 5% MV Adoption, 65% MV Ceiling



(i): MV yield growth = -0.41% *(ii): MV yield growth = 0.00%*
(iii): MV yield growth = 1.42% *(iv): MV yield growth = 2.00%*
Per capita rice demand

FIGURE 9: 2.05% Population Growth, 3% MV Adoption, 80% MV Ceiling

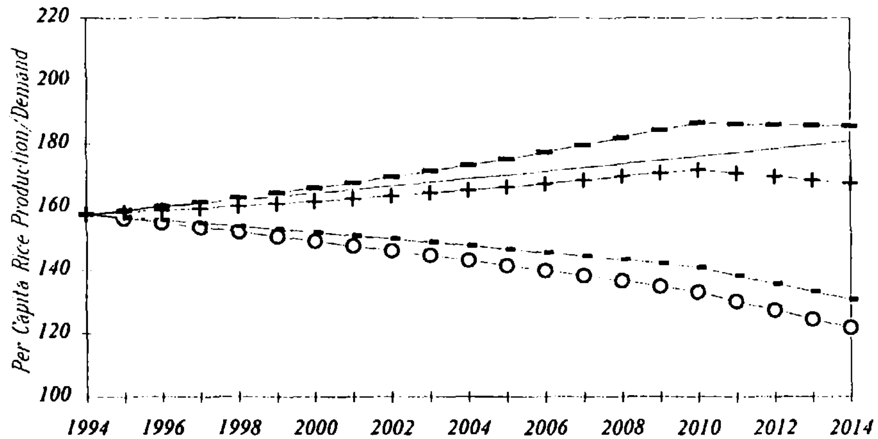


FIGURE 10: 2.05% Population Growth, 5% MV Adoption, 80% MV Ceiling

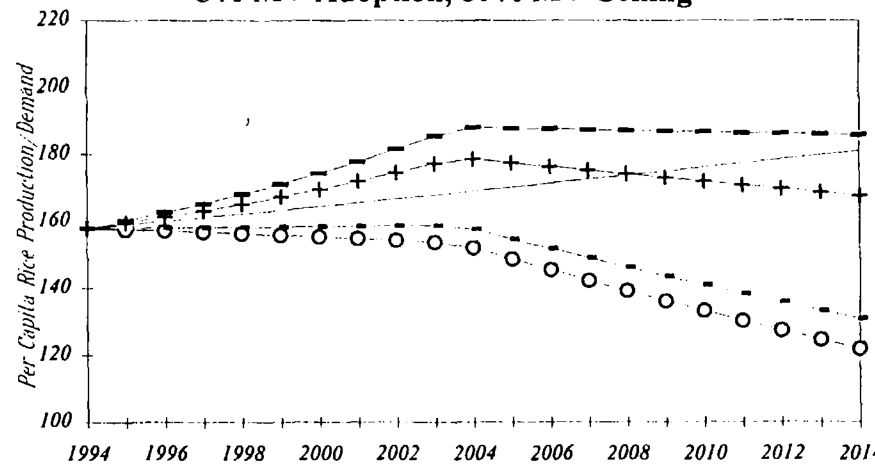


FIGURE 11: 1.49% Population Growth, 3% MV Adoption, 80% MV Ceiling

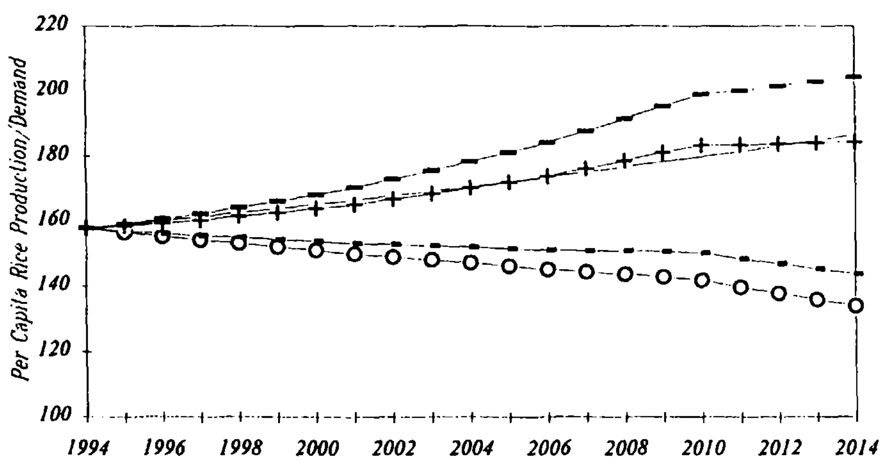
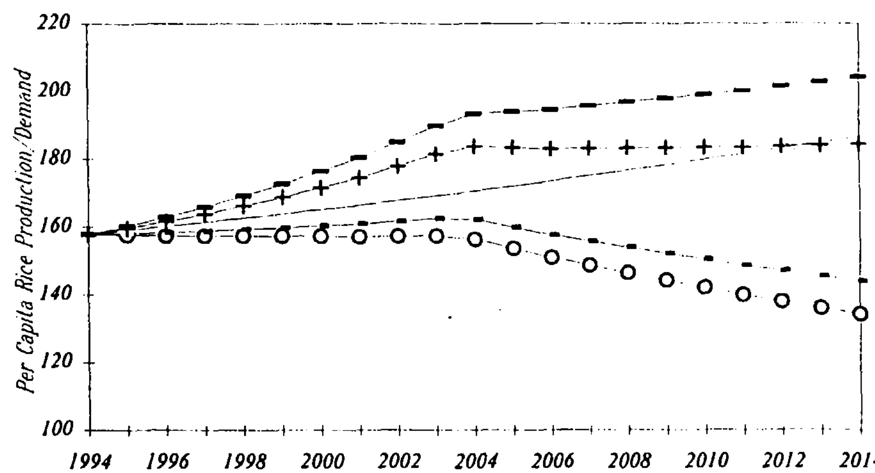


FIGURE 12: 1.49% Population Growth, 5% MV Adoption, 80% MV Ceiling



(i): MV yield growth = -0.41% *(ii): MV yield growth = 0.00%*
(iii): MV yield growth = 1.42% *(iv): MV yield growth = 2.00%*
Per capita rice demand

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APPENDIX A: KINKED GROWTH RATE REGRESSION

Consider regression (5),

$$\ln(Q_t) = \mu + \beta t + \varepsilon_t \qquad (A1)$$

and let k be the year in which a structural change has taken place. Typically, to account for such change (A1) is transformed as:

$$\ln(Q_t) = \mu_1 D + \mu_2(1-D) + \beta_1 Dt + \beta_2(1-D)t + \varepsilon_t \qquad (A2)$$

where D is a dummy variable taking the value of unity up to year k and zero elsewhere.

Since (A2) is equivalent to running two separate regressions, the trend lines may not necessarily intersect at the break point k. To eliminate this discontinuity we follow Boyce (1986) by imposing the following linear restriction:

$$\mu_1 + \beta_1 k = \mu_2 + \beta_2 k. \qquad (A3)$$

Restriction (A3) ensures that the trend lines intersect at k. Solving (A3) for μ_2, substituting the resulting expression in (A2), and rearranging terms results in:

$$\ln(Q_t) = \mu_1 + \beta_1(Dt+(1-D)k) + \beta_2(1-D)(t-k) + \varepsilon_t. \qquad (A4)$$

The hypothesis that $\beta_1 = \beta_2$ is then tested; rejection would indicate that a structural break did occur in year k. As Boyce has argued, in the absence of special circumstances (A4) is preferable to (A2). Further, (A4) has the advantage of ruling out the possibility that the growth rate derived from (A1) falls outside the interval (β_1, β_2) as derived from (A2).

APPENDIX B: GROWTH RATE ESTIMATES

Table B1. Constant Growth Rate Model

	Total Rice			*Modern Varieties*			*Local Varieties*		
	Output	*Area*	*Yield*	*Output*	*Area*	*Yield*	*Output*	*Area*	*Yield*
Annual									
μ	9.26	9.21	0.05	7.79	6.95	0.85	9.12	9.20	-0.08
	(526.1)	(905.9)	(3.27)	(132.1)	(126.5)	(54.08)	(205.9)	(266.0)	(-3.83)
β	0.0262	0.0020	0.0241	0.0751	0.0754	-0.0003	-0.0129	-0.0257	0.0128
	(19.52)	(2.63)	(19.62)	(16.71)	(18.04)	(-0.24)	(-3.83)	(-9.76)	(8.50)
R^2	0.95	0.26	0.95	0.93	0.94	0.01	0.42	0.83	0.78
ADF	-7.25	-2.54	-4.25	-5.86	-4.35	-3.41	-2.34	-1.60	-4.09
PP	-7.75	-2.74	-4.59	-2.85	-2.57	-3.80	-2.47	-1.55	-4.34
Aus									
μ	8.09	8.23	-0.14	6.40	5.45	0.95	7.86	8.17	-0.31
	(128.5)	(148.1)	(-6.44)	(36.86)	(29.70)	(31.47)	(136.9)	(150.5)	(-14.17)
β	-0.0137	-0.0269	0.0132	0.0195	0.0389	-0.0194	-0.0231	-0.0355	0.0123
	(-2.86)	(-6.37)	(7.76)	(1.48)	(2.78)	(-8.49)	(-5.29)	(-8.59)	(7.39)
R^2	0.29	0.67	0.75	0.10	0.28	0.78	0.58	0.79	0.73
ADF	-2.44	-1.05	-5.24	-5.16	-4.53	-3.01	-1.42	-1.32	-4.05
PP	-2.72	-1.68	-5.44	-4.28	-3.83	-3.23	-1.78	-1.33	-4.27
Aman									
μ	8.73	8.67	0.06	6.66	5.92	0.73	8.67	8.67	0.01
	(267.9)	(489.6)	(2.51)	(49.80)	(41.19)	(18.64)	(159.8)	(252.8)	(0.15)
β	0.0192	-0.0004	0.0196	0.0823	0.0820	0.0003	-0.0075	-0.0202	0.0127
	(7.75)	(-0.29)	(10.71)	(8.09)	(7.49)	(0.10)	(-1.81)	(-7.75)	(6.03)
R^2	0.75	0.01	0.85	0.77	0.74	0.01	0.14	0.75	0.65
ADF	-4.60	-2.98	-4.65	-3.99	-3.94	-4.22	-2.74	-2.33	-3.51
PP	-4.92	-3.08	-4.84	-2.71	-2.52	-4.48	-2.70	-1.89	-3.72
Boro									
μ	7.37	6.71	0.66	6.95	5.99	0.96	6.58	6.30	0.28
	(119.2)	(124.9)	(25.01)	(100.3)	(99.35)	(37.35)	(123.1)	(178.1)	(7.20)
β	0.0683	0.0540	0.0142	0.0867	0.0858	0.0010	-0.0307	-0.0349	0.0042
	(14.52)	(13.22)	(7.09)	(16.43)	(18.67)	(0.50)	(-7.55)	(-12.97)	(1.42)
R^2	0.91	0.90	0.72	0.93	0.95	0.01	0.74	0.89	0.09
ADF	-3.02	-2.54	-2.74	-3.76	-3.47	-3.91	-5.37	-5.53	-3.31
PP	-2.96	-2.51	-2.94	-2.40	-2.23	-4.04	-5.54	-5.92	-3.54

NOTES: The numbers in parentheses are *t*-values. ADF and PP refer to the augmented Dickey-Fuller and Phillips-Perron statistics. **SOURCE:** Authors' estimates. Original data from Bangladesh Bureau of Statistics.

Table B2. Kinked Growth Rate Model

	Total Rice			*Modern Varieties*			*Local Varieties*		
	Output	*Area*	*Yield*	*Output*	*Area*	*Yield*	*Output*	*Area*	*Yield*
Annual									
μ	9.26	9.19	0.08	7.82	6.94	0.88	9.04	9.12	-0.08
	(444.6)	(1079)	(4.59)	(113.0)	(106.6)	(61.48)	(239.8)	(475.6)	(3.26)
β_1	0.0257	0.0047	0.0209	0.0716	0.0757	-0.0041	-0.0013	-0.0142	0.0128
	(12.59)	(5.68)	(13.13)	(10.58)	(11.87)	(-2.96)	(-0.36)	(-7.59)	(5.63)
β_2	0.0280	-0.0082	0.0361	0.0884	0.0743	0.0141	-0.0560	-0.0689	0.0123
	(4.78)	(-3.41)	(7.89)	(4.55)	(4.06)	(3.55)	(-5.34)	(-12.29)	(1.87)
R^2	0.95	0.63	0.96	0.94	0.94	0.42	0.70	0.96	0.78
$F_{1,19}$	0.10	19.19	7.28	0.50	0.01	13.85	17.96	68.05	0.01
ADF	-7.60	-4.28	-7.55	-5.49	-4.38	-6.47	-3.28	-2.71	-4.08
PP	-8.71	-4.53	-7.87	-2.92	-2.57	-6.49	-3.42	-2.32	-4.33
Aus									
μ	7.89	8.09	-0.14	6.18	5.19	1.00	7.72	8.03	-0.31
	(192.1)	(376.9)	(-5.41)	(34.11)	(28.74)	(38.39)	(237.0)	(478.2)	(-11.79)
β_1	0.0059	-0.0072	0.0132	0.0504	0.0775	-0.0271	-0.0042	-0.0159	0.0116
	(1.46)	(-3.45)	(5.06)	(2.84)	(4.39)	(-10.65)	(-1.33)	(-9.65)	(4.75)
β_2	-0.0878	-0.1013	0.0135	-0.0972	-0.1068	0.0096	-0.0943	-0.1096	0.0153
	(-7.55)	(-16.78)	(1.81)	(-1.91)	(-2.11)	(1.32)	(-10.30)	(-23.21)	(2.09)
R^2	0.78	0.97	0.75	0.30	0.51	0.88	0.91	0.99	0.73
$F_{1,19}$	42.87	160.45	0.01	5.55	8.73	16.68	63.92	260.65	0.17
ADF	-5.05	-3.92	-5.26	-4.78	-4.37	-5.97	-4.92	-4.68	-4.12
PP	-5.13	-4.12	-5.46	-4.18	-3.89	-7.68	-5.24	-5.56	-4.33
Aman									
μ	8.74	8.66	0.08	6.75	5.98	0.77	8.60	8.61	-0.01
	(229.2)	(415.4)	(2.96)	(44.09)	(35.42)	(17.62)	(154.6)	(291.9)	(-0.17)
β_1	0.0172	0.0004	0.0168	0.0691	0.0740	-0.0049	0.0028	-0.0114	0.0142
	(4.61)	(0.21)	(6.32)	(4.61)	(4.48)	(-1.15)	(0.52)	(-3.95)	(4.43)
β_2	0.0268	-0.0035	0.0303	0.1320	0.1121	0.0199	-0.0462	-0.0537	0.0075
	(2.50)	(-0.59)	(3.98)	(3.07)	(2.36)	(1.63)	(-2.95)	(-6.48)	(0.81)
R^2	0.76	0.02	0.87	0.78	0.74	0.13	0.36	0.87	0.65
$F_{1,19}$	0.54	0.30	2.10	1.41	0.43	2.71	6.49	17.21	0.35
ADF	-4.88	-3.01	-5.75	-3.74	-3.75	-5.42	-2.97	-2.90	-3.46
PP	-5.34	-3.10	-6.34	-2.80	-2.49	-5.51	-2.91	-2.23	-3.64

Boro									
μ	7.40 (103.1)	6.75 (112.1)	0.65 (21.04)	6.96 (84.86)	6.00 (83.84)	0.97 (31.88)	6.56 (104.4)	6.31 (150.3)	0.26 (5.71)
β_1	0.0636 (9.05)	0.0474 (8.05)	0.0162 (5.37)	0.0849 (10.57)	0.0849 (12.13)	-0.0001 (-0.01)	-0.0279 (-4.54)	-0.0355 (-8.65)	0.0076 (1.73)
β_2	0.8600 (4.26)	0.0790 (4.67)	0.0071 (0.82)	0.0936 (4.06)	0.0889 (4.42)	0.0048 (0.56)	-0.0414 (-2.34)	-0.0328 (-2.78)	-0.0086 (-0.68)
R^2	0.92	0.91	0.73	0.93	0.95	0.02	0.75	0.89	0.14
$F_{1,19}$	0.82	2.29	0.73	0.10	0.03	0.21	0.38	0.04	1.10
ADF	-2.88	-2.48	-2.92	-3.66	-3.43	-3.80	-5.55	-5.53	-3.48
PP	-2.89	-2.48	-3.08	-2.37	-2.22	-3.95	-5.73	-5.95	-3.67

NOTES: $F_{1,19}$ is the *F*-statistic of the null hypothesis that the pre- and post-1986/87 growth rates are equal. Values higher than 4.34 and 8.18 imply rejection of the equality hypothesis at the 5 and 1% level of significance, respectively. For other notes see Table B1. **SOURCE:** Authors' estimates. Original data from Bangladesh Bureau of Statistics.

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