REGIONAL PRODUCTIVITY DIFFERENCES AND PROSPECT FOR CONVERGENCE IN BANGLADESH AGRICULTURE, 1964–1992[1]

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Abstract: *This paper applies the sequential Malmquist index to calculate multi lateral, multi-factor productivity (MFP) indices for agriculture in 16 regions of Bangladesh from 1964 to 1992 and examines convergence among regions. Productivity grew at an average rate of 2.2% per annum, led by regions with high level of Green Revolution technology diffusion. The growth mainly occurred due to technological progress estimated at 2.1% per year. Overall technical efficiency declined slightly at 0.1% per year due to falling technical efficiency in most of the regions in later years. Both cross-section and time series tests confirmed that divergence among regions disappeared and agricultural productivity reached convergence in the long run.*

JEL Classification: O4, Q1.

Keywords: Agricultural productivity, Regional variations, Convergence, Bangladesh

1. Introduction

Bangladesh, a predominantly agrarian economy, depend heavily on crop agriculture dominated by rice production occupying an estimated 70 percent of gross cropped area (BBS, 1996). Being a food deficit country, owing to its fast growing population in an already populated country, Bangladesh has pursued a policy of rapid technological progress in agriculture, leading to diffusion of a rice-based “Green Revolution (GR)” technology package. This led to a substantial increase in rice production from 1,504 thousand metric tons in 1968–70 to 18,211 thousand metric tons in 1992–94 (Rahman and Thapa, 1999). Use of modern inputs also dramatically increased from 8.8 kg of fertilizer nutrients per hectare in 1970 to 48.3 kg per hectare in 1994; a three-fold rise in the level of pesticide use from 2,200 metric tons in 1982 to 6,500 metric tons in 1994; and area under modern irrigation from zero in 1950 to 23.7 percent of gross cropped area in 1994 (Rahman, 1998). However, the current production scenario is not so encouraging on several counts. First, there has been a decline in the average yields of modern varieties (MVs) of rice. The yield levels of modern rice varieties have declined from 3.8 t/ha in 1968–70 (during the inception stage) to 2.4 t/ha in 1992–94 (the mature adoption stage), thereby raising doubts on the sustainability of food-grain production (Rahman and Thapa, 1999). Second, the adoption of GR technology seems to be stagnated. The observed increase in production at an annual rate of 2.34% during 1973–1999 is largely due to conversion from traditional rice to MVs rather than any increase in yields of MVs (Baffes and Gautam, 2001). Although the use of modern inputs in Bangladesh agriculture is far less than the world averages, the scope for increasing input use levels given a declining yield trend is limited, implying that increase in output to meet the growing food demand must rely on progress in technology and efficiency.

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The other major concern is the issue of regional variation in the growth patterns of food production. For instance, if the growth patterns of the regions diverge over time in response to variable adoption of GR technology, then this new technology itself will become an important source of disparity and exacerbate existing widespread poverty and inequality. Alauddin and Tisdell (1991) reported significant changes in growth rates in yield as well as production of foodgrain (rice and wheat) in the post-GR period (1969–1984). They attributed differences in the pattern of modern input use as the major source of regional disparity.

Studies on Total Factor Productivity (TFP) growth in Bangladesh crop agriculture is limited and results differ substantially (Table 1). The estimates vary from a TFP growth of 1.1 percent per annum in rice production to a decline of 0.23 percent per annum in crop agriculture depending on the period under study and methodology employed. Also, none examined the issue of convergence among regions in order to attain equal productivity levels in the long run, which is vital to reduce regional inequality and poverty.

[Insert Table 1 here]

Given this backdrop, the present paper applies a programming approach to the analysis of efficiency and productivity in agricultural sector in 16 regions of Bangladesh for the period 1964–1992 and tests for convergence among regions. The programming approach is appropriate because it requires only outputs and inputs, which are well recorded, as the market for major inputs, such as land and labor, in developing nations are not sufficiently developed to provide meaningful prices (Thirtle et al., 2003). The widely used form of Malmquist indices are constructed with respect to a *contemporaneous* frontier technology, in which the frontier in year *t*+1 is compared only with that for the previous year *t*, and all past history is ignored. This method provides unsatisfactory results when the number of observations in the cross-section is small relatively to the total number of inputs and outputs, known as the *dimensionality* problem, which is quite common. However, little attention has been paid to this problem in empirical studies not only in the agricultural sector but also more generally (for details, see Thirtle at al., 2003). In this study, we constructed regional-level Malmquist multi-factor productivity (MFP) indices based on a *sequential* frontier, which accumulates the data, as opposed to the conventional contemporaneous approach. This sequential frontier is constructed *each year* on the basis of all observations from the *first year up until the year considered*. In this paper, the data begins in 1962, but the first frontier estimate is for 1964, by which time there are 32 observations. In this formulation, in the context of an isoquant, the sequential frontier may only shift towards the origin, indicating technological progress, or remain static if there is no technological progress. Thus intersection of the frontiers are prohibited and technical knowledge is assumed to accumulate over time (Thirtle et al., 2003).

After constructing the MFP indices for the individual regions of the country, a test of convergence among regions is applied. Cross-section tests for Beta and Sigma convergence as well as panel-data tests based on time series techniques are utilized.

The paper is organized as follows. Section 2 discusses the methodology employed to construct MFP indices. Section 3 describes the data. Section 4 reports and interprets efficiency and MFP results. Section 5 presents the results of convergence tests among regions. Finally, Section 6 summarizes and concludes.

2. The sequential Malmquist index

The Malmquist productivity index, with respect to a sequential frontier, can be briefly described as follows (for details, see Thirtle et al., 2003 and Suhariyanto and Thirtle, 2001). Let region j = 1, 2, ... J use inputs $x^t \in R^N{}_+$ to produce outputs $y^t \in R^M{}_+$ during the period t = 1, 2, ... T. The production technology set can be defined as

$$S^{(1,t)} = \{(x^s, y^s) : x^s \; can\; produce\; y^s\}, s = 1 \; up\, until \;\; s = t \tag{1}$$

Alternatively, the production technology may also be represented by an input requirement set.

$$L^{(1,t)}(y^t) = \{x^t : (x^t, y^t) \in S^{(1,t)} \tag{2}$$

The within period input distance functions are defined as

$$D_i^s(y^t, x^t) = \max\{\lambda : (x^t / \lambda) \in L^{(1,t)}(y^t)\} \tag{3}$$

and

$$D_i^{s+1}(y^{t+1}, x^{t+1}) = \max\{\lambda : (x^{t+1} / \lambda) \in L^{(1,t+1)}(y^{t+1})\} \tag{4}$$

The value of these distance functions is equal to or greater than one, but conventionally, it is the reciprocals that are reported. Only if the value is equal to one are the districts efficient and therefore on the frontier. The adjacent-period input distance functions may also be defined as the following:

$$D_i^s(y^{t+1}, x^{t+1}) = \max\{\lambda : (x^{t+1} / \lambda) \in L^{(1,t)}(y^{t+1})\} \tag{5}$$

and

$$D_i^{s+1}(y^t, x^t) = \max\{\lambda : (x^t / \lambda) \in L^{(1,t+1)}(y^{t+1})\} \tag{6}$$

These four input distance functions are used to construct the Malmquist productivity index. The input oriented Malmquist productivity index for regions i between period s and s+1 is defined as (Fare et al., 1994):

$$M_i^{s,s+1} = \left(\frac{D_i^s(y^t, x^t)}{D_i^{s+1}(y^{t+1}, x^{t+1})} \right) \left(\frac{D_i^{s+1}(y^{t+1}, x^{t+1})}{D_i^s(y^{t+1}, x^{t+1})} \frac{D_i^{s+1}(y^t, x^t)}{D_i^s(y^t, x^t)} \right)^{1/2} \tag{7}$$

The ratio in the first bracket captures technical efficiency change (TEC) and the ratio in the second bracket provide a measure of technological change (TC). TEC is greater than, equal to or less than unity as technical efficiency improves, remains unchanged or declines between period s and s+1. TC is greater than or equal to unity and shows whether the frontier is improving or stagnant. Any technological regress is precluded by the accumulation of the past data in constructing this sequential frontier. This approach is appropriate in this study since it prevents the effects of serious flooding, common in Bangladesh, to be classified as technological regress. Instead, such effects are classified as efficiency losses, a more reasonable explanation. In other words, when Malmquist productivity index is constructed with respect to a sequential frontier, the flood causes efficiency losses and the index, which is a product of TEC and TC, fluctuates less (for details see Grifell-Tatje and Sintas, 1995).

3. Data

The data used for the analysis are adapted from Deb (1995). These are:

Aggregate crop output	= Includes all seasons and varieties of rice (*Aus*, *Aman*, and *Boro* – the pre-monsoon, monsoon and dry winter seasons), wheat, jute, sugarcane, potato, pulses, and oilseeds for each region. The variable is measured in values ('000 taka) estimated at constant 1984-85 prices.
Labor	= Labor engaged in agriculture is constructed from census data using linear trend extrapolation model.
Land area	= Area (in hectares) under all crops included in output is considered as the land area under cultivation. This measure of land area allows for changes in cropping intensity.
Animal power	= Number of draft animals is estimated using linear trend extrapolation from the livestock census data.
Fertilizer	= Total value of fertilizers (urea, phosphate, potash, and gypsum) distributed to each region at constant 1984-85 prices.
Irrigation	= Proportion of total land area under irrigation.

4. Technical efficiency, technical change and productivity

The multi-lateral agricultural MFP indices are calculated for 16 regions over the period 1964–1992. The Malmquist MFP indices are the products of technical efficiency change and technical change and are computed under the assumption of constant returns to scale. The index is constructed using a single output and five input technology where the inputs are labor, land, animal power, fertilizer and irrigation. Since, the programming technique as such do not provide information necessary on the choice of appropriate inputs, the variables were selected by estimating simple production function, which confirmed that all these inputs significantly affect output (for similar results, see Coelli et al., 2003 and Rahman, 2002).

4.1 Technical efficiency change

Technical efficiency is measured as the ratio of the actual level of input use to the best practice level, for each region, keeping output constant. The efficiency changes are calculated for each year of the sample period for each region using the sequential frontier. The results are summarized in Table 2 where the first column presents the initial level of efficiency in 1964. The next two columns present the chained efficiency change index (with 1964 as the base of 100) for the terminal year and the mean change over the 29-year period under study. The two regions, Bogra and Barisal tend to serve as the benchmark[1] for initial years, which are 100 percent efficient. None of the regions were operating at an efficiency level below 80 percent in 1964. However, the 1992 terminal efficiency changes in the next column reveals that efficiency levels declined for most of the regions, some substantially, while only two regions, Jessore and Kushtia experienced substantial efficiency improvements[2]. The overall level of efficiency change, reported in the third column are higher than the terminal year efficiency change implying that the fall in efficiency for most of the regions are drastic in the later years. The issue is discussed at length below.

[Insert Table 2 here]

4.2 Productivity growth

The efficiency change provides an incomplete picture of the situation as these are themselves function of the best practice frontier brought about by technical change, particularly widespread diffusion of rice-based GR technology package and corresponding improvement in modern irrigation facilities and rural infrastructure to support the diffusion process. The third column in Table 2 reports the terminal levels of chained technical change index, starting from a conventional base of 100. Three regions, Chittagong, Kushtia and Noakhali, seem to be the leaders with a terminal level technical change index of 226.1, 228.6, and 203.9, which are much higher than the technical progress of other regions. Diffusion of GR has been higher and faster in these three regions although all other regions followed suit in later years. Alauddin and Tisdell (1991) also reported that production of foodgrain grew at an annual rate of above 2.5 percent and yield at a rate of above 2 percent during 1969–1984. The overall level of technical change during the terminal year shows an increase of 67 percent, thereby indicating that the pursuit of GR diffusion as a priority policy has had positive effects.

The last two columns show the terminal and mean level of Malmquist MFP index. Kushtia stands out as the leader in productivity growth recording an impressive increase of 173.2 percent from its initial base of 100. Four of the 16 regions have lower MFPs than their 1964 levels, thereby confirming decline in productivity for these regions. The overall productivity improvement of Bangladesh is only 19.4 percent higher in 1992 than its initial level of 100 mainly driven by a decline in overall efficiency to 71.6 percent from its initial base of 100 in 1964.

The picture depicted in Table 2, although provides overall performance levels of each region, it does not show the complex dynamics driving these productivity results. Table 3 presents the average annual growth rates of Malmquist productivity indices and its components for each region classified by stages of GR diffusion. The period 1964–75 depicts the initial and introductory stage of GR that received priority through import of MV seeds in the late 1960s to support the accelerated food production program sponsored by Ford Foundation (Darlymple, 1986 cited in Hossain, 1989). Also, during the 1970s, large quantities of MV seeds were imported from International Rice Research Institute (IRRI) and neighboring India. In 1970 the Bangladesh Rice Research Institute (BRRI) was set up to develop varieties better suited to local growing conditions (Hossain, 1989). Soon after liberation of Bangladesh as an independent nation, the most prioritized agricultural development policy was to promote widespread diffusion of GR technologies with corresponding support in input delivery, research, extension and infrastructure facilities. In fact, use of MV seeds expanded at a rate of about 242,800 ha per year. The rice area under MV seeds just doubled in seven years and reached one-third of total rice area in 1985 (Hossain, 1989). Hence we termed the period 1976–1985 as the take-off stage of GR. The third stage is the mature stage of GR when stagnancy in the adoption of this technology package started to set in during late 1980s. There has been a concern that the ceiling level of adoption of GR technology in Bangladesh might have been reached (Berra and Kelly, 1990). Currently, 61 percent of total rice area are under MVs, while Baffes and Gautam (2001) optimistically predicted that the adoption level could reach up to 85 percent in the next decade. They assumed a minor increase in gross rice area whereas past experience actually revealed a stagnancy and/or minor decline in gross rice area.

[Insert Table 3 here]

Productivity growth was powered by different components at different stages of GR diffusion, which illustrates the complex dynamics in operation (Table 3). During the first 12 years (1964–1975), productivity grew at an annual rate of only 0.9 percent owing mainly to similar growth rate of technical progress and a slight decline in efficiency. The forerunners in this period were Chittagong, Bogra and Kushtia, while three other regions experienced MFP decline largely due to a decline in technical efficiency and negligible technical progress. Apparent lack of technical progress as well as decline in efficiency can be attributed to the biophysical constraints faced by these three regions. Barisal is a low lying riverine area with numerous *char* (delta) lands which yields one rice crop per year only. Faridpur is also prone to severe river-erosion as it sits on the bank of a major river Jamuna. Rangpur is a dry region located north of the country characterized by severe food shortage and high incidence of poverty.

During the take-off stage of GR (1976–1985), productivity grew at an annual rate of 2.27 percent mainly powered by technical efficiency improvements. Overall technical efficiency improved at an average rate of 1.5 percent per year during this period. The forerunners in this stage switched from the previous regions to new ones, except Kushtia. Productivity in Comilla region, which experienced efficiency decline in the first stage, recorded an impressive annual growth rate of 4 percent powered mainly by efficiency improvements. Noakhali also became the forerunner mainly through efficiency improvement as well as technical progress. Most of the regions revealed large efficiency improvements in this period. The backward regions (Barisal, Faridpur and Rangpur) also experienced high level of efficiency improvements but negligible technical progress. One possible explanation of efficiency improvement in most of the regions during this period is widespread use of few popular varieties developed by BRRI scientists in late 1970s. The commonly used MV rice seeds are BR1 (locally known as *Chandina*) grown mainly in *Boro* season (dry winter season, which is fully dependent on artificial irrigation) and BR11 (locally known as *Mukta*) grown in *Aman* season (the monsoon season, which provides bulk of the national rice output). These varieties are grown in consecutive years, thereby, leading to efficiency gains accrued from experience. In fact, several farm-level studies concluded that years of experience (commonly measured either by age or education of the farmer or both) contributes significantly to efficiency gain (for example, see Rahman, 2003; Sharif and Dar, 1996; Battese and Coelli, 1995). On the other hand, expansion in the delivery of modern inputs, irrigation facilities and other infrastructure support has been modest during this period, thereby, leading to a slow rate of overall technical progress.

During the mature stage of GR (1986–1992), the scenario changes dramatically. The sharp dip in the MFP index in 1990 and a subsequent jump to an unprecedented high level in 1991 as shown in Figure 1 is due to the major natural disaster that struck Bangladesh in 1988. An estimated 64 percent of the country's land area was under flood for several months causing massive livestock deaths, infrastructure and crop damages in addition to human casualties. However, flood also brings in blessing, perhaps as compensation from the nature after wrecking havoc. Once the floodwater receded, the croplands were replenished with silted alluvium drawn from the riverbeds and the following year recorded a dramatic rise in crop production, popularly termed as "bumper" production. During this mature stage of GR adoption, except four new regions including Kushtia, all other regions showed high level of efficiency decline whereas technical progress was very high. The constraints affecting efficiency, which was mainly attributed to biophysical reasons during the 1960s, seem to be insufficient in providing an adequate explanation at this stage. The overall efficiency decline was recorded at 2.6 percent while technical progress occurred at an annual rate of 6.1 percent.

As a result, total productivity of the nation grew at an annual rate of 4.5 percent during this period. Despite high levels of productivity growth, five regions experienced productivity decline driven by sharp fall in efficiency. Kushtia and Faridpur were the forerunner during this period followed by Jessore and Rangpur. It is interesting to note that two of the most backward regions, Faridpur and Rangpur, were among the high productive regions now. The reasons may be rapid expansion of irrigation area at an annual rate of 18–19 percent per year and an increase in fertilizer usage at an annual rate of 13–15 percent (Rahman, 2002).

[Insert Figure 1 here]

The overall rate of productivity growth for the nation as a whole is 2.2 percent per annum during the 29-year period under study (1964–1992) mainly powered by technical progress at an annual rate of 2.1 percent and slight decline in efficiency (-0.13 percent per annum).

The dynamic behavior of efficiency change during the three stages of GR adoption can be attributed to a host of factors including natural disaster, such as flood. As discussed in Section 2, given our sequential frontier model, natural disasters and shocks are more realistically represented by a fall in efficiency rather than technical regress, which are revealed in Tables 3 and 4. Table 4 presents the overall scenario for productivity growth and its components by year. It is clear from Table 4 as well as Figure 2 that the drastic fall in efficiency is recorded just after the massive flood of 1988 which was not recovered since then. On the other hand, productivity was on the rise from take-off stage of GR, except in 1990.

[Insert Table 4 and Figure 2 here]

The initial decline in efficiency corresponds with the improvement in the technology index as expected. However, as the same MVs spread to less suitable land, the yield level of MVs fell. For example, the coastal, central and north-eastern regions have been stagnant in their growth performance since the take-off stage of the GR and continued to be so although there is no difference in level of technology adoption as compared to the fast growth regions (Ahmed, 2001). The intensive use of modern inputs in these less advantaged areas did not produce the same level of increase in output and efficiency differences increased leading to TFP decline. Another reason may be depletion of nutrients from soil due to higher nutrient uptake in the form of rice harvest exacerbated further with the use of lower than recommended level of fertilization to replenish the soil. Baanante et al., (1993) noted that the present level of food crop production in Bangladesh takes up an estimated 0.93 million tons of nutrients (N, P, K, and S). Ahmed (2001) estimated that total level of fertilizer use for rice production is about 40–45 percent below the recommended levels, and for phosphate and potassium fertilizers, in particular, the rates are 60–70 percent lower than recommended dose. Another factor contributing to falling efficiency and TFP is the re-use of MV rice seeds from one generation to the next, which inherently leads to lower levels of productivity since genetic purity is compromised. In principle, these self-pollinated MVs require replacement in 4–5 years to maintain their productivity, which are not strictly followed by farmers in general.

5. Testing convergence among regions

Convergence occurs when regions with poorer productivity level during the initial period grow more rapidly than regions with high initial level of productivity implying that the poorer regions are catching up. This is a major concern for Bangladeshi government since the nation is traditionally a food deficit country, which led to rapid diffusion of Green Revolution technology throughout in order to improve production as well as welfare of the poor and marginal farming population. Figure 1 suggests that none of the regions are producing at a significantly higher level of productivity and, hence the MFP growth is contributed by most of the regions although there are slight variation in regional productivity levels. In other words, there is no evidence of significant divergence among regions. However, firm decision can only be arrived by formally testing for convergence using a variety of methods as discussed below.

Both cross-section and time series methods of testing convergence have been used extensively in the literature (Thirtle et al., 2003). The cross-section method examines the tendency of regions/countries with initial low level productivity to grow relatively faster in order to catch up with those of high initial level productivity. Therefore, if the growth rates are regressed on the initial level of productivity and the coefficient is negative, there is said to be Beta convergence. The average growth rate of productivity for each region *i* between year 0 and T can be defined as $g_{i,T} = T^{1} (y_{i,t} - y_{i,0})$. Then, a test of Beta convergence is conducted by a regression of growth rate as the dependent variable with the initial level of productivity as the regressor as follows:

$$g_{i,t} = \alpha + \beta y_{i,0} + \varepsilon_{i,T} \tag{8}$$

where α and β are parameters and $\varepsilon_{i,T}$ is an error term with a zero mean and finite variance. Convergence exists if the value of β is negative and significant. The result of this exercise is presented in Table 5. The estimated parameter β, which is the coefficient of the initial level of productivity level, is negative and significant at 1 percent confidence level. This provides strong evidence that agricultural productivity in Bangladesh has converged. In other words, regions with initial poor level of productivity grew faster and are catching up with the high productive regions.

[Insert Table 5 here]

Another simple cross-section test for convergence is the Sigma convergence, which holds if the cross-sectional standard deviations of the log of MFP decrease over time. In other words, it tests whether the productivity differences among regions are narrowing over time. Technically, a necessary condition for Sigma convergence is the existence of Beta convergence although Beta convergence does not guarantee a reduction in the distribution of dispersion among MFP growth rates (Thirtle et al., 2003). Figure 3 shows that the cross-sectional standard deviations for the log of MFP over time are in fact fluctuating within a narrow range, which further corroborate the result obtained from Beta convergence test.

[Insert Figure 3 here]

An alternative approach for testing convergence, based on time series properties, was proposed by Bernard and Durlauf (1995). In this proposition, convergence is tested by examining, whether the long-run forecasts of productivity differences tends to zero as the forecasting horizon tends to infinity. Hence, long-run convergence is achieved when there is equality of productivity among regions. The Augmented Dicky-Fuller (ADF) and cointegration analyses are used to test the time series properties of convergence.

Let A_{it} represent agricultural MFP in region *i, i = 1, 2, ... n*, at time *t*. The regions on the frontier may vary each period, and those with the highest level of MFP, in any year, form the reference group, with which all other regions are compared. This best practice group is termed as the frontier economy *f*, which may be a single region. MFP is assumed to develop according to (Thirtle et al., 2003):

$$\ln A_{it} = \gamma_i + \lambda \ln\left(\frac{A_{ft-1}}{A_{it-1}}\right) + \ln A_{it-1} + \varepsilon_{it} \tag{9}$$

where γ_i is the rate of growth of region *i*. The parameter λ characterizes the speed of catch up, which is a function of the productivity differential between region *i* and region *f* and ε_{it} is the error term. Equation (9) implies that productivity in each region *i* may potentially grow either as a result of sector-specific growth or as a result of technology transfer. If region *i* is the most productive region, there is no technology transfer and Eq. (9) becomes:

$$\ln A_{ft} = \gamma_f + \ln A_{ft} - 1 + \varepsilon_{ft} \tag{10}$$

Combining equations (9) and (10), gives the expression for relative MFPs on which the tests are based,

$$\ln\left(\frac{A_{it}}{A_{ft}}\right) = (\gamma_i - \gamma_f) + (1-\lambda)\ln\left(\frac{A_{it-1}}{A_{ft-1}}\right) + \hat{\varepsilon}_{it} \tag{11}$$

Equation 11 can be estimated directly and the ADF test with a drift is used to perform the test. If there is no catching-up ($\lambda=0$), the difference between MFP in region *i* and in region *f* will contain a unit root (non-stationary). This means that productivity levels will permanently grow at different rates and there is no evidence of convergence. In contrast, if $\lambda>0$, the difference between the technology levels in the two regions will be stationary, indicating evidence of convergence, implying that productivity differences should vanish in the long run. The drift term ($\gamma_i - \gamma_f$) will typically be small but non-zero, if there is no evidence of convergence. Under the hypothesis of convergence, $\gamma_i = \gamma_f$ is plausible. Therefore, only if $\lambda>0$, and $\gamma_i = \gamma_f$, the regions will converge.

Table 6 reports the results of the unit root test of Equation 11 for panel data using the techniques described by Levin and Lin (1993). The coefficient on the lagged agricultural MFP, i.e., the term (1 – λ), is –1.5905, which indicates that the value of λ is 2.5905. The t-statistics rejects the null hypothesis of a unit root and, therefore, dispersion of productivity is stationary providing strong evidence that the regions do exhibit long-run convergence. Further, the drift term ($\gamma_i - \gamma_f$) is approximately zero. The null hypothesis that the drift term is zero cannot be rejected at 1 percent confidence level, thereby confirming that $\gamma_i = \gamma_f$. Therefore, both the conditions of $\lambda>0$ and $\gamma_i = \gamma_f$ hold in our case and, therefore, jointly confirms that there is strong evidence of long-run convergence among regions. Thus the unit root tests support the conventional tests and the final conclusion is that there is convergence among regions in Bangladesh agriculture, a source of relief on the part of the government. The similar pattern of productivity growth rates among regions over time as shown in Figure 1 is entirely confirmed by the tests.

[Insert Table 6 here]

6. Conclusions and policy implications

This paper applies the sequential Malmquist index to calculate multi-lateral, multi-factor productivity (MFP) indices for agriculture in 16 regions of Bangladesh from 1964 to

1992 and examines convergence among regions. The MFP indices reveal that productivity in Bangladesh agriculture grew at an average rate of 2.2% per annum, led by regions with high level of Green Revolution technology diffusion. The overall productivity growth mainly occurred due to technological progress estimated at 2.1% per year. Overall technical efficiency declined slightly at 0.1% per year due to falling technical efficiency in most of the regions in later years. The growth performances were highly variable across regions over time. During the inception stage of the GR diffusion (1964-1974), technical progress were slow and all the regions were operating at high level of efficiency equipped with their traditional technologies. Some of the regions experienced efficiency decline during this period leading to an overall modest productivity growth of 0.9% per annum. During the take-off stage of GR diffusion (1975-1984), productivity growth was mainly powered by efficiency improvements while technical progress was still modest resulting in a productivity growth at a rate of 2.3% per annum. During the mature stage of GR diffusion (1985-1992), the scenario changed dramatically. Record rise in technical progress was observed while efficiency declined dramatically in 12 out of 16 regions. However, productivity growth was still impressive recording a growth rate of 4.5% per annum for this period. The principle contributory factor behind rapid technical progress during this period is the widespread expansion of modern irrigation technology and use of modern inputs of fertilizers as well as dramatic rise in pesticide application. On the other hand, corresponding decline in efficiency during this period is perhaps due to a number of inter-related factors. These are, expansion of rice area in unfavorable and marginal lands; dramatic rise in cropping intensity dominated by rice monoculture; genetic impurity of self-pollinated MV seeds from reuse due to lack of replacement; high nutrient uptake in the form of rice harvest; and significantly lower use rate of fertilization than the recommended doses leading to a decline in soil fertility.

Both cross-section and time series tests confirmed that divergence among regions disappeared and agricultural productivity reached convergence in the long run. This is a sign of relief on the part of the policy makers as it implies potential reduction in regional inequality and pervasive poverty in the long-run. On the other hand, dramatic decline in efficiency during the later years raises concern on the future productivity potential to feed the growing population unless rapid technical progress continues to offset the detrimental effect of falling efficiency. Another cause of concern is the steadily declining yield performance of MV rice seeds during the later years on which the total GR technology package is based. The evidence of long run convergence among regions is perhaps hiding the fact that, it is the slowing down of fast growing regions to match the growth performance of slow growing regions rather than the latter catching up with the former.

The policy implication is that Bangladesh need to focus on promoting new technologies rather than relying on GR technology alone and should urgently address the cause of drastic fall in efficiency in agricultural sector in recent years. Previous thrust in GR diffusion over the past four decades has paid off to a large extent, and there is a need to widen the policy arena to choose from a wide range of technologies in order to sustain existing performance and to increase production potential of the nation. For example, "hybrid rice" offers bright prospects to increase rice productivity (Ahmed, 2001). Policy to promote crop diversification away from rice monoculture as a source of sustained production growth also worth pursuing. Considerable potential exists for crop diversification provided that all other requisites are in place. For example, non-cereal crops such as potatoes, vegetables, onions and cotton show economic and private returns which are as high as or higher than MV rice (Mahmud et al., 1994). But, expansion of these crops are associated with high price and marketing risks in addition to incompatible water management system, which currently prevents non-cereals to be planted together with rice crops (Mahmud et al., 1994). Also, major thrust in R&D activities in Bangladesh is to produce adaptive modern varieties of rice only, which can be further widened to exploit technological potential of non-cereal crops[3]. Other important areas of policy thrust are development of water management system suited to multi-purpose use, promotion of effective input delivery system, and soil conservation measures, which will remain a challenging task for the policy makers in the future as well.

Notes

1. Choice of a suitable peer is a source of concern in programming approach. However, since Bangladesh is predominantly a rice producing country, the peer group is natural as the regions constitute the country and the choice is not expected to affect the results.
2. Since these are chained indices, any value less than 100 percent indicates decline in efficiency and vice versa.
3. For an up-to-date list of rice varieties released from BRRI, see Ahmed (2001): Table 7.5.

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Table 1. Productivity growth rates in Bangladesh agriculture from available studies

Source	Sector	Period	Data type	Approach	TFP growth rates (%)
Pray and Ahmed (1991)	Crop	1948 – 81	Regional panel	Index number (T-T)	0.32
Dey and Evenson (1991)	Crop	1952 – 71	Regional panel	Index number (T-T)	0.09
		1973 – 89			0.94
Ahmed (2001)	Rice	1976 – 98	National aggregate	Index number (T-T)	1.10
Suhariyanto and Thirtle (2001)	Agriculture	1965–1996	Cross-country	Sequential Malmquist (MFP)	-0.12
Coelli et al., (2003)	Crop	1961 – 92	Regional panel	Parametric (SF)	-0.23

Note: T-T = Tornqvist-Theil Index
SF = Stochastic frontier
MFP = Malmquist Factor Productivity

Table 2. Technical efficiency change, technical change and productivity levels by region

Region	Efficiency level	Efficiency change (TEC)		Technical change (TC)		Productivity (MFP)	
	1964	1992	Mean	1992	Mean	1992	Mean
Barisal	100	45.1	73.1	122.4	103.9	55.2	75.9
Bogra	100	67.2	91.6	186.5	114.6	125.3	105.0
Chittagong	87.8	59.5	105.6	226.1	132.9	134.4	140.4
Comilla	95.1	46.7	92.2	178.2	114.1	83.2	105.2
Dhaka	88.1	83.8	95.5	161.6	111.5	135.4	106.4
Dinajpur	81	78.1	109.0	152.7	112.4	119.3	122.5
Faridpur	99.8	97.2	79.0	131.4	103.4	127.7	81.7
Jessore	85.6	116.8	97.6	157.7	105.7	184.2	103.2
Khulna	92.7	59.2	84.7	151.8	105.6	89.9	89.5
Kushtia	82.9	119.5	100.0	228.6	124.5	273.2	124.5
Mymensingh	90.1	97.2	100.7	160.4	108.2	156.0	108.9
Noakhali	96.1	49.9	92.9	203.9	127.4	101.8	118.3
Pabna	80.7	62.7	89.2	159.9	108.7	100.2	97.0
Rajshahi	85.9	65.2	95.3	163.1	110.1	106.4	104.9
Rangpur	95.3	101.5	97.0	173.1	108.9	175.6	105.6
Sylhet	80.9	53.9	100.3	147.5	110.3	79.5	110.7
Bangladesh	**90.1**	**71.6**	**93.5**	**166.7**	**112.3**	**119.4**	**105.1**

Table 3. Annual growth rates (percent) of the Malmquist productivity index and its components

Region	First 12 years (1964-1975)			Take-off stage (1976-1985)			Mature stage (1986-1992)			Whole period (1964-1992)		
	TEC	TC	MFP	TEC	TC	MFP	TEC	TC	MFP	TEC	TC	MFP
Barisal	-2.21	0.86	-1.33	2.32	0.16	2.47	-7.15	2.50	-5.04	-1.84	1.02	-0.92
Bogra	2.14	1.23	3.69	1.32	0.97	2.34	-4.91	7.47	1.54	0.16	2.65	2.71
Chittagong	1.33	2.67	4.00	-0.11	2.62	2.53	-7.62	5.79	-3.25	-1.33	3.40	1.74
Comilla	-1.13	1.08	-0.01	3.42	0.58	4.01	-8.30	7.07	-1.37	-1.29	2.35	1.05
Dhaka	-0.66	0.97	0.34	1.76	0.86	2.76	-0.68	5.56	6.69	0.17	2.04	2.71
Dinajpur	0.42	1.20	1.61	0.53	0.19	0.72	-3.98	4.95	1.13	-0.61	1.76	1.19
Faridpur	-1.75	0.07	-1.64	1.79	0.11	1.90	10.14	4.02	17.96	2.34	1.04	4.31
Jessore	0.95	0.13	1.10	1.07	0.31	1.39	4.50	6.92	14.57	1.85	1.83	4.45
Khulna	0.76	0.46	1.25	1.55	0.09	1.63	-6.98	6.42	-1.01	-0.84	1.77	0.83
Kushtia	-0.05	2.20	2.15	3.23	0.92	4.19	4.78	9.36	20.00	2.25	3.49	7.16
Mymensingh	-0.22	0.41	0.19	1.60	0.83	2.44	-0.12	6.10	7.96	0.43	1.93	2.84
Noakhali	0.03	1.13	1.20	1.74	2.31	4.19	-7.70	6.54	-3.44	-1.25	2.84	1.11
Pabna	0.00	0.33	0.37	2.23	0.60	2.82	-3.33	5.98	3.86	-0.04	1.79	2.06
Rajshahi	0.30	0.42	0.74	0.31	0.38	0.69	-5.52	6.65	1.22	-1.10	1.91	0.84
Rangpur	-0.97	0.42	-0.55	1.46	0.33	1.80	2.16	8.31	14.06	0.62	2.29	3.79
Sylhet	0.11	0.77	0.86	0.02	0.56	0.49	-7.11	4.20	-3.06	-1.66	1.53	-0.21
Bangladesh	**-0.06**	**0.90**	**0.87**	**1.52**	**0.74**	**2.27**	**-2.62**	**6.12**	**4.49**	**-0.13**	**2.10**	**2.23**

Table 4. The Malmquist productivity index and its components by year

Year	Efficiency change	Technical change	Malmquist index
1964	100.00	100.00	100.00
1965	99.29	100.19	99.48
1966	101.39	101.17	102.57
1967	94.95	101.27	96.16
1968	98.97	101.79	100.75
1969	96.65	102.66	99.22
1970	100.30	103.41	103.72
1971	92.28	103.61	95.61
1972	93.88	103.59	97.26
1973	95.78	104.19	99.80
1974	96.28	106.62	102.65
1975	88.96	106.74	94.96
1976	91.90	107.71	98.99
1977	89.21	108.53	96.82
1978	96.29	109.68	105.62
1979	96.56	109.70	105.93
1980	93.94	109.89	103.22
1981	96.53	110.94	107.09
1982	93.81	112.40	105.44
1983	95.16	113.33	107.84
1984	98.61	113.78	112.20
1985	100.13	114.72	114.87
1986	102.41	119.78	122.66
1987	99.00	120.15	118.96
1988	97.83	120.71	118.09
1989	97.06	122.10	118.50
1990	68.87	123.49	85.04
1991	76.20	166.27	126.70
1992	71.63	166.69	119.41

Table 5. Testing for Beta convergence

Period	Variable	Coefficient	SE	t-statistics	R-squared
1964 – 1992	α	14.853	1.824	8.14***	0.14
	β	-14.618	1.661	-8.79***	

Note: *** = significant at 1 percent level (p<0.01).

Table 6. Time series test for convergence

Period	Variable	Coefficient	SE	t-statistics
1964 – 1992	$(\gamma_i - \gamma_f)$	0.00001	0.00163	0.000
	$(1 - \lambda)$	-1.59055	0.08255	-20.857***

Note: *** = significant at 1 percent level (p<0.01).

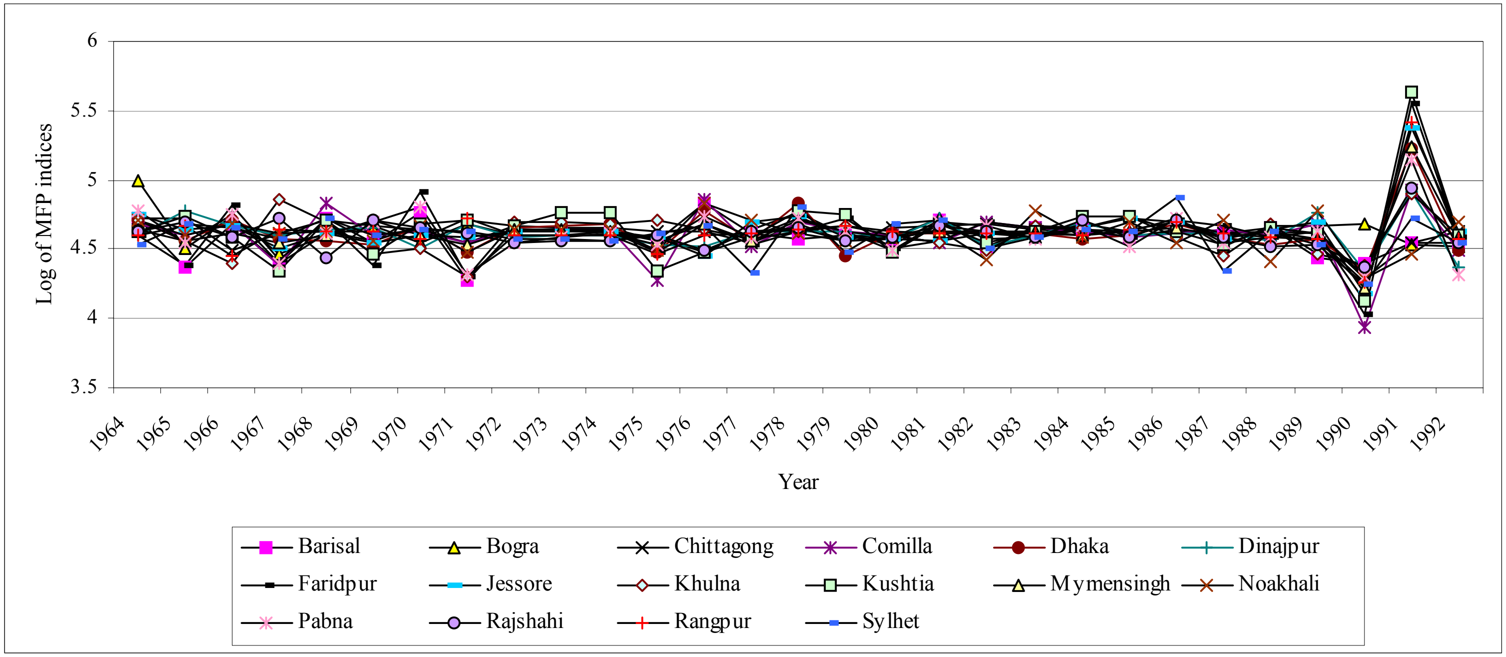

Figure 1. Logarithms of agricultural MFP indices by region.

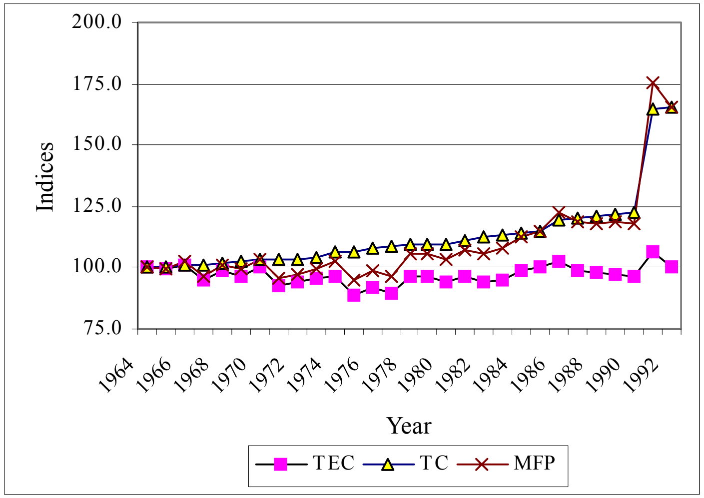

Figure 2. Technical efficiency change, technical change and Malmquist productivity.

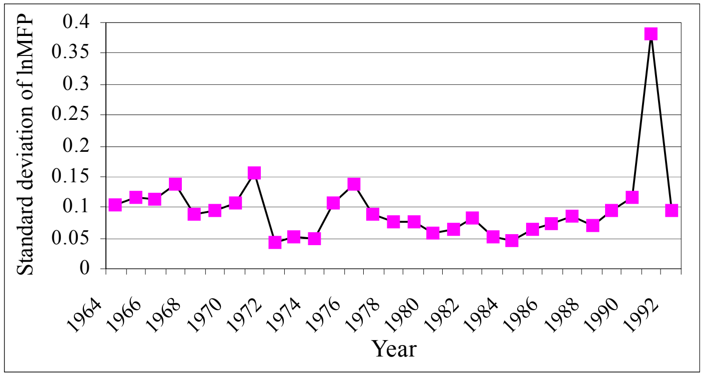

Figure 3. Sigma convergence: Standard deviations of the logarithm of MFP index.