TECHNOLOGICAL INNOVATION AND TOTAL FACTOR PRODUCTIVITY GROWTH OF RICE PRODUCTION IN BANGLADESH IN THE POST-LIBERALISATION ERA

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Abstract: *The objective of this study was to assess the impact of technological innovation on the total factor productivity (TFP) growth of rice in Bangladesh during the post liberalisation era. The study used data from secondary sources and estimated the Data Envelopment Analysis (DEA)-based Malmquist productivity index for assessing the TFP-growth. It also estimated the Cobb-Douglas (C-D) production function using Ordinary Least Square (OLS) regression method for assessing determinants of rice output. The study found that agricultural trade liberalisation positively influenced the TFP-growth of rice through technological innovation in the post-liberalisation era. The increase in the TFP-growth was driven by technological innovation – a cropping shift from local varieties to high yielding varieties (HYV) of rice and reallocation of resources in favour of the HYV-dominated Boro rice production. However, after the first decade the TFP-growth gradually slowed down, which was attributed to the technological contraction or non-improvement and negative productivity of labour. The study suggests that the government should formulate policies to increase investment in research and development for technological innovation, and in human resource development through training and agricultural extension services for the efficient use of inputs to improve TFP-growth in rice production in the future.*

Keywords: *Total factor productivity (TFP), Malmquist productivity index, rice production, post-liberalisation, Bangladesh*

JEL classification code: *C63, F14, O47*

1. Introduction

Bangladesh went through a series of deregulation and agricultural trade liberalisation measures in the late 1980s and early 1990s with a view to increasing productivity in agriculture and achieving self-sufficiency in food-grain production. Major reforms in agricultural policy included liberalisation of input markets, shrinking the role of government agencies in the distribution of inputs, substantial reduction and rationalisation of tariffs, removal of quantitative restrictions, moving from a multiple to a unified exchange rate, and shifting from a fixed to a flexible exchange rate system (N. Ahmed, Bakht, Dorosh, & Shahabuddin, 2007, p. 9; S. Ahmed & Sattar, 2004, pp. 11, 12; Hoque & Yusop, 2010, p. 39; M. I. Hossain & Verbeke, 2010, p. 78; Islam & Habib, 2007, p. 4; Moazzem, Ahmed, Manzur, & Chowdhury, 2012, p. 9; Salim & Hossain, 2006, p. 2569). Agricultural trade liberalisation generated significant impacts on major structural reforms and technological innovation in rice production, enabling the country to achieve self-sufficiency in food-grain production in the early 1990s (S. Ahmed & Sattar, 2004, p. 19; Faroque, Kashem, & Bilkis, 2013, p. 2; Islam & Habib, 2007, p. 4; Klytchnikova & Diop, 2006, p. 3). Although other factors might also have affected the growth in output, agricultural trade liberalisation was the most important policy reform because of households' critical dependence on rice in terms of both income and consumption.

In Bangladesh, amongst agricultural products, rice is dominant in terms of volume of production and cultivated areas. Therefore, farmers use the main proportion of agricultural inputs such as fertilisers, pesticides, irrigation, and seeds for rice cultivation (Anderson, 2004, p. 1; Klytchnikova & Diop, 2006, p. 5; Ministry of Agriculture, 2007; OECD, 2010, p. 11). Rice captured the largest share of the agricultural sector, accounting for 75 percent of the total crop production value, 63 percent of total crop sales, and 75 percent of total cultivated area of the country in 2005 (Klytchnikova & Diop, 2006, p. 13; Ministry of Agriculture, 2007). In addition, rice is the staple food in the economy. Agricultural trade liberalisation influenced the volume of rice production significantly through a technological transformation (combination of irrigation, fertilisers, and HYV seeds). The study assumed rice as the representative of agriculture, thereby, considering analysis of the impact of agricultural trade liberalisation on productivity of rice.

Bangladesh was a large country in terms of the size of its population (164 million) with a very high density – 1246 people per sq km in 2010. However, it was a very small economy in terms of gross domestic product (GDP) (89.38 billion US dollars) and gross national income (GNI) per capita (590 US dollars) in the same year (Ministry of Finance, 2012; World Bank, 2011a, 2011b). Agriculture played an important role in supplying food as well as in maintaining food security of this very large and fast-growing population. The food security and self-sufficiency in food grain production of the economy depends mainly on how agricultural trade liberalisation impacted productivity of rice in the post-liberalisation era and how farmers would response to rice production in the future. Therefore, the main objective of this study is to examine the impact of technological innovation on the TFP growth of rice in the post-liberalisation era with a view to suggesting a policy framework for the government to cope with the food security and food production issues in the future.

The following sections include agricultural trade liberalisation scenarios in Bangladesh, a literature review, a methodology and research design, discussion and analysis of results, and conclusions.

2. Agricultural Trade Liberalisation Scenarios in Bangladesh

Like many other developing countries in the world, Bangladesh had pursued inward-looking policies and strategies for trade and development since its independence in 1971. These policies involved high government interventions in almost all economic activities, including agriculture (N. Ahmed, et al., 2007, pp. 2, 7; Draper & Sally, 2005, p. 3; Hoque & Yusop, 2010, p. 1; Rahman, 2008, p. 5). Bangladesh encouraged cooperative farming with a view to developing a socialist system of agriculture during the 1970s. The government controlled the procurement and distribution of seeds, fertilisers, pesticides, irrigation equipment and all other agricultural inputs (N. Ahmed, et al., 2007, pp. 2, 7; S. Ahmed & Sattar, 2004, p. 11; Salim & Hossain, 2006, p. 2568).

The government adopted import substitution policies with restrictions on imports in order to protect and support domestic production. It controlled the foreign trade and exchange rate system for making interventions effective (S. Ahmed & Sattar, 2004, p. 11; Krueger, 2010, p. 2; Nahar & Siriwardana, 2009, p. 327; Salim & Hossain, 2006, p. 2568). A series of measures including quantitative restrictions, highly differentiated tariff rates (ranging from 0 to 400 percent), huge production subsidies, and overvalued exchange rates were put in place to protect domestic production from world competition (N. Ahmed, et al., 2007, p. 7; S. Ahmed & Sattar, 2004, p. 11; Nahar & Siriwardana, 2009, p. 327; Salim & Hossain, 2006, p. 2568).

The government reinforced this protective environment with domestic market policy interventions in the form of credit ceilings, price controls, and arbitrary licensing such as import licences. These licences were granted only when there was no domestic source of supply available (N. Ahmed, et al., 2007, p. 19; Islam & Habib, 2007, pp. 10, 14; Krueger, 2010, p. 2; Salim & Hossain, 2006, p. 2568). Moreover, traditionally, the Bangladesh Agricultural Development Corporation (BADC) – had the sole authority and responsibility for procurement and distribution of agricultural inputs including fertilisers, irrigation equipment, pesticides and seeds (N. Ahmed, et al., 2007, pp. 19, 21; Islam & Habib, 2007, pp. 10, 14; Rahman, 2008, p. 13; Salim & Hossain, 2006, p. 2568).

However, these inward-oriented trade policies were not successful in terms of trade expansion or import substitution. These policies did not result in a sustained increase in productivity. Rather, the gap between demand for and supply of agricultural goods widened over the years (N. Ahmed, et al., 2007, p. 7; Hoque & Yusop, 2010, p. 39; Salim & Hossain, 2006, p. 2568). With a growing dissatisfaction regarding inward-looking trade and development policies, the sustainability of government interventions towards long-term food-grain availability was questioned due to the increased inefficiency and corruption in the public management system and the heavy budgetary burden imposed by these operations (N. Ahmed, et al., 2007, pp. 6, 7; Dorosh & Shahabuddin, 2002, p. 38; Hoque & Yusop, 2010, p. 39; Krueger, 2010, p. 5; Salim & Hossain, 2006, p. 2569).

Realising such inefficiencies as well as constant pressures from the donor countries and international development agencies such as the World Bank and the IMF, the government started to pursue a policy-shift from state intervention to more market-oriented policies in the mid 1980s with a view to achieving high economic growth and reducing poverty (N. Ahmed, et al., 2007, p. 9; Hoque & Yusop, 2010, p. 39; M. I. Hossain & Verbeke, 2010, p. 78; Islam & Habib, 2007, p. 3; Nahar & Siriwardana, 2009, p. 327; Rahman, 2008, p. 11; Salim & Hossain, 2006, pp. 2567, 2569). Deregulation and agricultural trade liberalisation generated a momentum that began in the late 1980s and peaked in the early 1990s.

Similarly, the government pursued a wide range of policy reforms to liberalise agricultural input markets including privatisation of the distribution system of key agricultural inputs, initiatives for deregulation measures to improve the investment climate for private enterprises, gradual elimination of subsidies on fertilisers and small irrigation equipment, and improving the maintenance of agricultural equipment through encouraging participation of the private sector (M. U. Ahmed, 2004, pp. 11, 12; N. Ahmed, et al., 2007, p. 9; Klytchnikova & Diop, 2006, p. 3; Salim & Hossain, 2006, p. 2569).

As a consequence of these reforms, the fertiliser trade was almost entirely handled by the private sector in 2005 (N. Ahmed, et al., 2007, pp. 19, 20; S. Ahmed & Sattar, 2004, pp. 13, 19; Klytchnikova & Diop, 2006, p. 3; Salim & Hossain, 2006, p. 2569). Further policy reforms included the rationalisation or elimination of import duties on agricultural inputs and spare parts, elimination of the government monopoly in fertiliser imports, and abolition of standardisation requirements (N. Ahmed, et al., 2007, pp. 19, 20; S. Ahmed & Sattar, 2004, pp. 13, 19; Klytchnikova & Diop, 2006, p. 3; Salim & Hossain, 2006, p. 2569).

There were encouraging responses to these liberalisation and reform initiatives from market forces. Therefore, the private sector participation in the input market rose sharply. Irrigation equipment became cheaper and farmers had easy access to the equipment. Different types of high yielding variety (HYV) seeds were available to farmers, thereby promoting both extensive and intensive cultivation by increasing the irrigated area and use of fertilisers (Klytchnikova & Diop, 2006, p. 3; Salim & Hossain, 2006, p. 2569).

Consequently, agricultural trade liberalisation generated significant impacts on economic growth through productivity improvement in the agricultural sector. It contributed to technological innovation in agriculture, leading to productivity improvement of agricultural inputs (S. Ahmed & Sattar, 2004, p. 19; Islam & Habib, 2007, p. 4; Klytchnikova & Diop, 2006, p. 3). The reform measures – including liberalisation of the input markets for fertilisers, pesticides, and irrigation equipment and adoption of high yielding variety seeds for rice production – led to major structural reforms and technological transformation, resulting in a significant increase in productivity and growth in the agricultural sector. Technological changes in agricultural production enabled the country to achieve self-sufficiency in food grain production in the early 1990s (S. Ahmed & Sattar, 2004, p. 19; Islam & Habib, 2007, p. 4; Klytchnikova & Diop, 2006, p. 3). The rising volume of rice production was accompanied by a decline in rice prices during 1990-2009. Moreover, because of significant structural transformation and technological changes, productivity of this sector was at its highest level (BBS, 2009, p. 3; Klytchnikova & Diop, 2006, p. 2; Ministry of Finance, 2010, p. 84).

These structural transformations reflected the government’s efforts to open the economy, liberalise agricultural trade and reform domestic markets in the 1980s and 1990s (S. Ahmed & Sattar, 2004, p. 12; Klytchnikova & Diop, 2006, p. 2). They enabled the economy to achieve a significant growth in the 1990s – increase in real GDP by an average of 4.2 percent per year and significant increases in agricultural production (Klytchnikova & Diop, 2006, p. 2; Salim & Hossain, 2006, p. 2570).

3. Literature Review

Agricultural trade liberalisation in Bangladesh refers to reducing trade barriers that have been created over a number of years. These barriers are created to protect domestic agricultural production from competition of foreign producers (Agbeyegbe, Stotsky, & WoldeMariam, 2006, p. 261; Duncan & Quang, 2003, p. 15; Feenstra & Taylor, 2008, p. 272; Krueger, 2009, p. 37; Krugman & Obstfeld, 2006, p. 223; Panagariya, 2009, p. 557; Turner, Nguyen, & Bird, 2008, p. 15). These barriers include a complex and opaque assembly of instruments and regulations including various trade controls (such as tariffs, variable levies, import and export subsidies, quotas and other non-tariff barriers), price support measures, income transfers, production subsidies, investment grants etc. (Eicher, Mutti, & Turnovsky, 2009, pp. 144, 145; Feenstra & Taylor, 2008, p. 272; Husted & Melvin, 2007, p. 148; Krugman & Obstfeld, 2006, p. 186). Trade liberalisation has gained popularity since David Ricardo's analysis of comparative advantage which explains how trade will benefit economies with differences in opportunity costs of production (Amoroso, Chiquiar, & Ramos-Francia, 2011, p. 1; Rahman, 2008, p. 1; Whaples, 2006, p. 1; Zhang, 2008, p. 25).

As per arguments for trade liberalisation, agricultural trade liberalisation is likely to direct scarce resources into areas of Bangladesh's comparative advantage, promote specialisation resulting in higher productivity and growth, accelerate investment by allowing access to bigger markets and permit economies of scale, and encourage imports of previously unavailable or scarce capital goods and intermediate inputs for agriculture (S. Ahmed & Sattar, 2004, p. 1; McCulloch, Winters, & Cirera, 2003, pp. 15, 16; Montalbano, 2011, p. 1; Stone & Shepherd, 2011, p. 5; Zhang, 2008, p. 175). Liberalisation of import markets for fertilisers, pesticides and irrigation equipment might have facilitated farmers' access to the improved production technology, and enabled Bangladesh's agriculture to reallocate resources for specialisation in efficient rice crop cultivation (S. Ahmed & Sattar, 2004, p. 1; McCulloch, et al., 2003, pp. 15, 16; Montalbano, 2011, p. 1; Stone & Shepherd, 2011, p. 5; Zhang, 2008, p. 175).

Advocates of free trade argue that agricultural trade liberalisation would produce a knowledge spill-over effect through technological innovation that is embodied in imported machinery, leading to higher growth in Bangladesh's agriculture. This growth would enhance returns to the economy's relatively abundant factor of production – the unskilled labour – by raising real wages for them, thereby contributing to an improvement in income distribution (S. Ahmed & Sattar, 2004, p. 2; Gabre-Madhin, Barrett, & Dorosh, 2002, p. 2; Islam & Habib, 2007, p. 4; Klytchnikova & Diop, 2006, p. 6; Lee & Vivarelli, 2006, p. 7).

In Bangladesh, amongst agricultural products, rice is dominant in terms of staple food, volume of production and cultivated areas. Therefore, farmers use the main proportion of agricultural inputs such as fertilisers, pesticides, irrigation, and seeds for rice cultivation. From the theoretical point of view, agricultural trade liberalisation may affect productivity of rice farmers through technological transformation.

Since the 1980s, the re-emergence of the neo-classical orthodoxy as an important development paradigm, Bangladesh adopted agricultural trade liberalisation and market reform programmes (Gingrich & Garber, 2010, p. 2; Meijerink & Roza, 2007, p. 6; Meschi & Vivarelli, 2009, p. 287; Rahman, 2008, p. 11; Salim & Hossain, 2006, p. 2567). This paradigm is based on the argument and belief that agricultural trade liberalisation contributes to growth through facilitating technological innovation and re-allocation of productive resources (R. Chang, Kaltani, & Loayza, 2005, p. 2; McCulloch, et al., 2003, pp. 15, 16; Montalbano, 2011, p. 1; Stiglitz, 2003, p. 59; Stone & Shepherd, 2011, p. 5; Zhang, 2008, p. 175). There are arguments that agricultural trade liberalisation contributes to technological transformation and improves productivity of agricultural inputs allowing competition and efficient factor-allocation, leading to higher economic growth (Henry, Kneller, & Milner, 2009, p. 237; McCulloch, et al., 2003, p. 25; San Vicente Portes, 2009, pp. 944, 945; Stiglitz, 2003, p. 59; Stone & Shepherd, 2011, p. 5). The technological transformation is due to improved access to imported inputs, machinery and knowledge, leading to an increase in productivity (Foster, 2008, p. 545; Henry, et al., 2009, p. 237; Lipton, 2006, p. 60; McCulloch, et al., 2003, p. 25; Meijerink & Roza, 2007, p. 10). These arguments further suggest that the agricultural input market becomes more competitive through diffusion of modern production technology and knowledge in agriculture as a result of agricultural trade policy reforms (Foster, 2008, p. 545; Henry, et al., 2009, p. 237; Lipton, 2006, p. 60; McCulloch, et al., 2003, p. 25; Thirtle, Irz, Lin, McKenzie-Hill, & Wiggins, 2001, p. 4).

The achievement of significant growth in agriculture, particularly in rice production, induced by technological innovation was demonstrated in many Asian countries through the green revolution since the 1960s that spread rapidly as a demonstration effect throughout the region in the 1970s and 1980s, especially in densely populated regions (Adeoti & Sinh, 2009, p. 7; Barichello, 2004, pp. 2, 6; Byerlee, Diao, & Jackson, 2005, p. 1; Meijerink & Roza, 2007, p. 2). It is argued that the success of East Asian countries such as Japan, South Korea and China in rice production was generated by technological breakthrough in the form of high-yielding varieties of rice in association with farmers' access to fertilisers and irrigation, which provided a significant improvement in productivity growth (Adeoti & Sinh, 2009, pp. 6, 7; Byerlee, et al., 2005, p. 9; IFAD, 2002, p. 63). The East Asian success was a source of inspiration for many developing countries, including Bangladesh, to liberalise input sectors. This initiative was based on the objective to improve productivity of rice through technological innovation. Redistribution of resources via relatively efficient public school systems played an important role in technological transformation. East and Southeast Asian countries generated more competent governments than in South Asia and sub-Saharan Africa. In particular, they achieved much higher literacy rates among rural populations, and hence were able to profit from modern agricultural technologies to a much greater extent than South Asian countries.

Many studies attempted to shed light on productivity of rice in Bangladesh. Some of these major studies on this effect include: Rice Price Stabilization on Bangladesh: An Analysis of Policy Options (Dorosh & Shahabuddin, 2002); Trade Liberalisation and the Crop Sector in Bangladesh (M Hossain & Deb, 2003); Poverty Alleviation Through Agriculture and Rural Development in Bangladesh (Mahabub Hossain, 2004); Market Deregulation, Trade Liberalisation and Productive Efficiency in Bangladesh Agriculture: An Empirical Analysis (Salim & Hossain, 2006); Trade Reforms, Farm Productivity, and Poverty in Bangladesh (Klytchnikova & Diop, 2006); Impact of Shallow Tube-wells and Boro Rice on Food Security in Bangladesh (Mahabub Hossain, 2009); Evaluation of Rice Markets Integration in Bangladesh (M. I. Hossain & Verbeke, 2010); Welfare Impact of Policy Interventions in the Foodgrain Markets in Bangladesh (Alam, Buysse, Begum, Wailes, & Van Huylenbroeck, 2011); Factors Influencing Adoption, Productivity and Efficiency of Hybrid Rice in Bangladesh (Azad & Rahman, 2017); Financial Profitability and Resource Use Efficiency of Boro Rice Cultivation in Some Selected Area of Bangladesh (Sujan, Islam, Azad, & Rayh, 2017); and Government Input Support on Aus Rice Production in Bangladesh: Impact on Farmers' Food Security and Poverty Situation (Uddin & Dhar, 2018). However, these studies did not attempt to assess the TFP-growth in rice production in the post-liberalisation era, which is the main focus of this study.

4. Methodology and Research Design

The study used annual time series data from secondary sources. The main source was Handbook of Agricultural Statistics, December 2007 *(*Ministry Agriculture, 2007).

Other sources include BBS (2007) and Bangladesh Economic Review (Ministry of Finance, 2009-2015).

The study measured total factor productivity (TFP)-growth of rice. TFP-growth shows the relationship between the growth of output and the growth of input with the influence of technology and technical efficiency. It is generally calculated as a residual (Englander, 1988, p. 6; Hisali & Yawe, 2011, p. 14). Solow (1957) introduced the measurement of productivity growth and technical progress which was associated with a production function/cost function/profit function.

For the TFP-growth measurement, economists developed many techniques such as index number approaches including Malmquist productivity index (Caves, Christensen, & Diewert, 1982, p. 1394; Färe & Grosskopf, 1992, p. 158), Solow's residual (Raa & Shestwova, 2006, p. 3; Solow, 1957, p. 312), Törnqvist productivity index (Caves, et al., 1982, p. 1394) , and Fisher ideal index (Färe & Grosskopf, 1992, p. 158); stochastic production frontier estimation techniques (Sharma, Sylwester, & Margono, 2007, p. 218); Monte Carlo simulation techniques (Slade, 1986, p. 76); translog production function (T. Chang & Hu, 2010, p. 3263); growth accounting matrix (Griliches, 1996, p. 1324); and Durenberger productivity indicator (Barros, Guironnet, & Peypoch, 2011, p. 642).

Both mathematical and econometric models are used to measure TFP-growth. Using mathematical models, there are four main approaches to the measurement of TFP-growth namely: (a) Solow's residual analysis, (b) the index number approach, (c) input-output analysis, and (d) Data Envelopment Analysis (DEA) (Raa & Shestwova, 2006, p. 1).

The Malmquist productivity index is a widely-used index number approach because it is simple to measure, easy to understand, and produces reliable results. It provides high accuracy, has minimum restrictions for model specification, and is easy to decompose into two major components: technical efficiency change, and technological change – the main sources of TFP-growth. Similarly, the DEA method is a commonly used technique for the measurement of TFP-growth. The main advantage of using the DEA method is that it avoids model misspecification (Cook & Zhu, 2005, p. 1). This is a scale-neutral method using the measurement of inputs and outputs based on linear programming techniques. (T. Chang & Hu, 2010, p. 3263).

This study used the DEA method to calculate the Malmquist productivity index (TFP) with a view to identifying sources of productivity growth and efficiency in rice production. The advantage of the DEA-based Malmquist productivity index is that it calculates the efficiency of factors or inputs. The output-oriented factor-efficiency measures the maximum output from a given input. Similarly, input-oriented efficiency measures the use of minimum input to produce a given output. It is related to returns to scale such as increasing, constant, and decreasing return to scale.

This study adopted the pioneering works of Färe and Grosskopf (1992), and Färe *et al.* (1994) as below:

The production possibility set-

$$S^t = \{(x^t, y^t): x^t \; can \; produce \; y^t\},$$

where time period t = 1, 2 ...T. The technology is assumed to have standard properties such as convexity. The production (output) sets are defined in terms of S^tas:

$$P_t(x) = \{y^t: (x^t, y^t) \in S^t\}.$$

The successive production sets are essentially independent from each other. However, there is a certain form of dependence between sequential production sets across time. This dependence is based on the assumption that production units can always produce the same amount of outputs given the same amount of inputs what they have done before in the production processes (Färe & Grosskopf, 1992, p. 159; Färe, et al., 1994, p. 68; Yuk-Shing, 1998, p. 7). Thus, the construction of the latest set requires information on the previous period's inputs and outputs for measuring productivity performance.

In order to calculate the Malmquist productivity index using sequential DEA approach, the output distance function for each time period, *t*, can be written as follows:

$$d^t(x^t, y^t) = \min\left\{\lambda : \left({y^t}/{\lambda}\right) \in p_t^{seq}(x^t)\right\};$$

where superscript p_t^{seq} denotes sequential output set. When λ is minimised, then y^t/λ is maximised. Thus, this distance function measures the maximum possible output with a given input vector x^t and technology under period t. Therefore, the Malmquist productivity index can be defined as follows (Färe & Grosskopf, 1992, p. 159; Färe, et al., 1994, p. 70):

$$M(x^t, y^t, x^{t+1}, y^{t+1}) = \frac{d^t(x^t, y^t)}{d^{t+1}(x^{t+1}, y^{t+1})} \times \left[\frac{d^{t+1}(x^t, y^t)}{d^t(x^t, y^t)} \times \frac{d^t(x^{t+1}, y^{t+1})}{d^{t+1}(x^{t+1}, y^{t+1}}\right]^{1/2};$$

where, in the right hand side of the equation, the ratio outside the square brackets measures the change in technical efficiency between two periods (years), *t* and *t+1*. The geometric mean of the two ratios inside the square brackets captures the shift in technology between the two periods. In order to calculate output-oriented Malmquist productivity index under the assumption of constant return to scale (CRS) technology four distance functions are required to be calculated as follows:

$$\left[d_c^{t+i}(x_{\acute{k}}^{t+j}, y_{\acute{k}}^{t+j})\right]^{-1} = \max_{\theta, z_k^s} \theta^{\acute{k}},$$

subject to

$$-\theta^{\acute{k}} y_{\acute{k},m}^{t+j} + \sum_{s=1}^{t+i}\sum_{k=1}^{K} z_k^s y_{k,m}^s \geq 0, \quad m = 1, \ldots\ldots, M$$

$$x_{\acute{k},n}^{t+j} - \sum_{s=1}^{t+i}\sum_{k=1}^{K} z_k^s x_{k,n}^s \geq 0, \quad n = 1, \ldots\ldots, N$$

$$z_k^s \geq 0, \quad k = 1, \ldots\ldots, K, and\ s = 1, \ldots\ldots, T+i,$$

The symbol θ denotes a scalar of the proportional expansion in output for a given input vector and z_k^s is an intensity variable indicating at what intensity production unit k may be employed in production. The symbol M represents total output, implying a non-negative output constraint. The symbol N represents total input, implying a non-negative input constraint. The symbol K represents total number of farms and T represents total time periods, implying non-negative constraints of farms and time period. It is required to solve a linear programming problem to calculate each of the distance functions as follows:

$$\left[d_c^t(x_{\acute{k}}^t, y_{\acute{k}}^t)\right]^{-1} \quad is\ calculated\ with\ (i,j) = (0,0);$$

$$\left[d_c^{t+1}(x_{\acute{k}}^{t+1}, y_{\acute{k}}^{t+1})\right]^{-1} is\ calculated\ with\ (i,j) = (1,1);$$

$$\left[d_c^t(x_k^{t+1}, y_k^{t+1})\right]^{-1} \quad is\ calculated\ with\ (i,j) = (0,1);$$

$$\left[d_c^{t+1}(x_k^t, y_k^t)\right]^{-1} \quad is\ calculated\ with\ (i,j) = (1,0);$$

where subscript c denotes the CRS benchmark technology. A short intuitive explanation on the Malmquist productivity index is included in Appendix A.

This study also estimated the Cobb-Douglas (C-D) production function to determine the returns to scale and the elasticity of output with a view to cross-checking the robustness of results of the DEA-based Malmquist productivity index. It has used a log-linear OLS regression model for the convenience of measuring the partial elasticity of output with respect to a particular input (labour or capital) (Greene, 2007, p. 890; Gujarati, 2006, p. 174; Maddala, 2008, p. 112). The C-D production function can be written as follows:

$$Y = AL^{\propto}K^{\beta};$$

where *Y* is total output, *L* is labour input, *K* is capital input, *A* is technology, and α and β are the partial elasticities of labour and capital respectively. These values are constant and are determined by available technology. Further, if:

(α + β)
- *> 1: increasing return to scale;*
- *= 1: constant return to scale; and*
- *< 1: decreasing return to scale*

The above equation can be re-written as follows:

$$Y = \beta_1 X_{2t}^{\beta_2} X_{3t}^{\beta_3}$$

This equation can be expressed as a log-transformation or log-linear regression model as follows:

$$LnY = Ln\beta_1 + \beta_2 LnX_{2t} + \beta_3 LnX_{3t} + u_t;$$

where u_t is the error term.

The study disaggregated capital input into irrigation, fertilisers, pesticides and seeds with a view to identifying their individual impact on rice output. It also included land in the model because land is an important factor of rice production. Therefore, the model can be re-written as follows:

$$LnY = Ln\beta_1 + \beta_2 LnX_{2t(land)} + \beta_3 LnX_{3t(labour)} + \beta_4 LnX_{4t(irrigation)} + \beta_5 LnX_{5t(fertilisers)} + \beta_6 LnX_{6t(pesticides)} + \beta_7 LnX_{7t(seeds)} + u_t;$$

The study used data from secondary sources for a period between 1986-87 and 2005-06 to achieve its objectives. The main source of secondary data includes the *Handbook of Agricultural Statistics 2007* (Ministry of Agriculture, 2007), and *Bangladesh Economic Review* 2008, 2009 and 2010 (Ministry of Finance, 2008, 2009, 2010). It also used data from various statistical yearbooks of Bangladesh Bureau of Statistics (BBS). These data were in both aggregated and disaggregated forms, such as total rice production (aggregated) and distribution of total rice production by three main rice crops – Aus, Amon, and Boro (disaggregated).

5. Result Discussion and Analysis

5.1. Descriptive Statistics of Data

The descriptive statistics represents the basic characteristics of data–whether the distribution of data (annual) is normal and symmetric or not. The descriptive statistics of input and output of rice– the mean, standard deviation, skewness and kurtosis–are presented in Table 1.

The values of standard deviations for all variables are large, suggesting that the data are dispersed away from the mean over a large range of values. The skewness values for variables irrigation, fertilisers and labour are negative, indicating that the distribution is left skewed or a large proportion of data are distributed on the right side of the mean with extreme values to the right, suggesting that the mean is smaller than the median. Conversely, these values for variables rice output, land and pesticides are positive, indicating a right skewed distribution of data, where the mean is greater than the median.

The kurtosis value for seeds is greater than 3, suggesting a leptokurtic distribution of data – sharper than a normal distribution, with values concentrated around the mean and thicker tails, indicating high probability for extreme values. The kurtosis values for all other variables are much smaller than 3, suggesting a platykurtic distribution of data – flatter than a normal distribution with a wider peak. In this case, the probability for extreme values is less than for a normal distribution and the values are widely spread around the mean as indicated earlier by high values of standard deviation for these variables.

Therefore, this study argues that data are not symmetric and not normally distributed around the mean, suggesting that a translog or log-linear model would be more effective to fit a regression line than a model without having a log transformation. The main advantage of log transform is to make a distribution more normal than the original distribution of data, while the ratio of each observation remains unchanged. Because a log-transformation reduces the effects of extreme values, thereby making the distribution of data more symmetric than the original data set.

Table 1: Descriptive statistics of input and output of rice production data: 1986-87 to 2014-15

Variables	Mean	Std. Deviation	Skewness	Kurtosis
Rice output (000 tonnes)	19634.650	3750.176	.617	-1.092
Land (000 hectare)	10378.221	280.558	.126	-1.058
Irrigation (000 hectare)	3047.779	714.937	-.029	-.811
Fertilisers (000 tonnes)	2670.200	705.520	-.339	-.792
Seeds (000 tonnes)	403.105	34.841	-1.978	3.495
Pesticides (000 tonnes)	10.737	5.223	.172	-1.332
Labour (000)	21772.538	2608.950	-1.019	-.237

Source: Authors' calculation using data from Table 1.03, 2.01, 4.01, 4.03, 4.08, 4.15, 5.05 and 7.03, (Ministry of Agriculture, 2007) and Statistical Year Book of Bangladesh (various years)

5.2. Total Factor Productivity Growth of Rice

Total factor productivity (TFP)-growth of rice measures the proportion of output, which is not explained by the amount of inputs used in rice production. Using the Data

Envelopment Analysis (DEA) method, the Malmquist productivity index is calculated to analyse the TFP-growth of rice in Bangladesh. The DEA-based Malmquist productivity index measures the changes in TFP-growth over time. It is decomposed into two main components – technical efficiency change (TE) and technological change (TC). The TFP-growth index represents the multiplicative impacts of these two components. Technical efficiency measures farmers' ability to produce the maximum output (rice) possible from a given set of inputs and production technology. On the other hand, technological change measures the frontier shift – the shift in production possibility frontier (PPF). It represents technological progress (outward shift of PPF) or contraction (inward shift of PPF). Thus, a TFP-growth level is determined by how efficiently and intensely the inputs are utilised in rice production as well as by the level of technological change. If the value of TFP-growth is greater than one then it represents progress in productivity and vice versa. Similarly, a unitary value of TFP-growth implies no change in productivity.

Bangladesh experienced a positive change in the TFP-growth of rice immediately after agricultural trade liberalisation as shown in Table 2. TFP-growth increased from 1986-87 through to 1998-99 then declined gradually. The value of TFP was greater than one over the period 1990-91 to 1998-99 suggesting that the TFP-growth of rice improved during this period, indicating an increasing return to scale in rice production. On the other hand, the value of TFP-growth was less than one for the period 1999-2000 to 2014-15, implying that there was a decline in productivity of rice during that period and suggesting a decreasing return to scale in rice production. The frontier shift or TC showed a trend similar to changes in TFP-growth – it started to increase immediately after liberalisation and slowed down after 1998-99. The value of TC was greater than one during 1988-89 to 1997-98 suggesting that Bangladesh experienced technological progress in rice production during this period. However, during the other periods – 1986-87 to 1988-89 and 1999-2000 to 2014-15 – the value of TC was less than one, indicating that there was a technological contraction or non-improvement during that period. Noticeably, the value of TE was close to one over two decades from 1986-97 to 2005-06, implying that there was little change in technical efficiency over that period. Over thirty years from 1986-87 to 2014-15 the mean value of TFP was 0.96 – close to one, implying that Bangladesh experienced an average increase in the TFP-growth of rice during that period on average. Similarly, the mean value of TC was 0.98 indicating that, on average, there was a technological progress, implying an outward shift of production possibility frontier during that period. The mean value of TE for that period was close to one (0.96), suggesting that there was a positive-but-insignificant technical efficiency change over that period. However, one of the shortcomings of the Malmquist index of TFP is that it cannot specify exactly how much (e.g. percent) the change was.

Table 2: Total factor productivity of rice in Bangladesh: 1986-87 to 2014-15

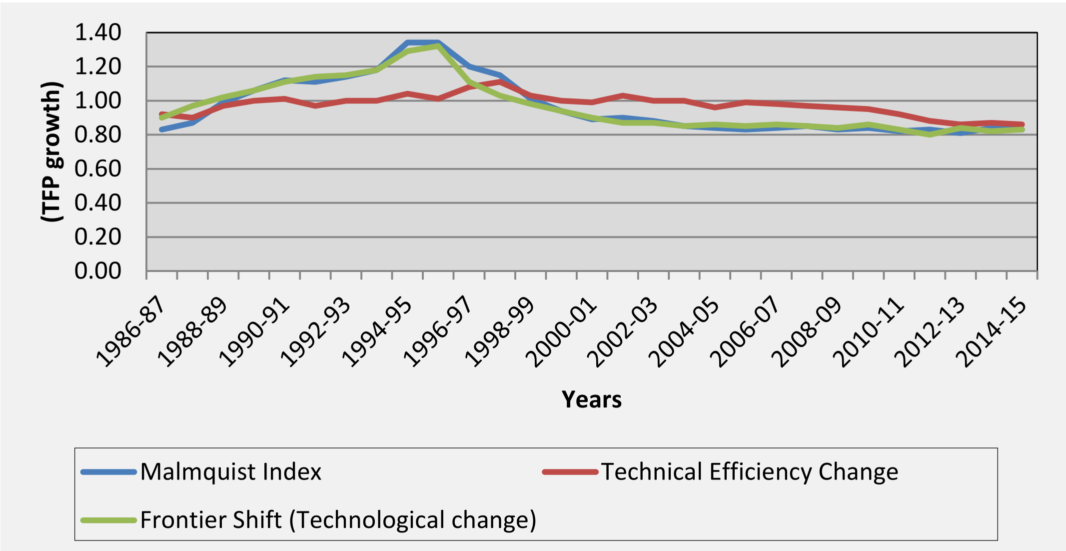
Year	Malmquist Index (Total Factor Productivity)	Technical Efficiency Change	Frontier Shift (Technological change)
1986-87	0.83	0.92	0.90
1987-88	0.87	0.90	0.97
1988-89	0.99	0.97	1.02
1989-90	1.06	1.00	1.06
1990-91	1.12	1.01	1.11
1991-92	1.11	0.97	1.14
1992-93	1.14	1.00	1.15
1993-94	1.18	1.00	1.18
1994-95	1.34	1.04	1.29
1995-96	1.34	1.01	1.32
1996-97	1.20	1.08	1.11
1997-98	1.15	1.11	1.03
1998-99	1.01	1.03	0.98
1999-00	0.94	1.00	0.94
2000-01	0.89	0.99	0.90
2001-02	0.90	1.03	0.87
2002-03	0.88	1.00	0.87
2003-04	0.85	1.00	0.85
2004-05	0.84	0.96	0.86
2005-06	0.83	0.99	0.85
2006-07	0.84	0.98	0.86
2007-08	0.85	0.97	0.85
2008-09	0.83	0.96	0.84
2009-10	0.84	0.95	0.86
2010-11	0.82	0.92	0.83
2011-12	0.83	0.88	0.80
2012-13	0.81	0.86	0.84
2013-14	0.84	0.87	0.82
2014-15	0.83	0.86	0.83
Mean	0.96	0.98	0.96

Note: The preceding year is used as the base year for TFP growth calculation

Source: Authors' calculation using data from Table 1.03, 2.01, 4.01, 4.03, 4.08, 4.15, 5.05 and 7.03, (Ministry of Agriculture, 2007) and Statistical Year Book of Bangladesh (various years)

The above analysis suggests that the progress in the TFP-growth of rice immediately after agricultural trade liberalisation was driven by technological progress not by technical efficiency in rice production. This argument is evident from Figure 1. TFP-growth increased along with TC during 1986-87 to 1995-96. However, during 1995-96 to 1998-99, TC declined more sharply than TFP-growth making a significant gap between TFP and TC and suggesting that TE influenced TFP-growth more than TC for this period. This argument is supported by a sharp rise of TE over that period. From 1998-99 through to 2014-15, both TFP-growth and TC were below TE and the gap between TFP and TC was minimal suggesting that technological change influenced TFP-growth of rice in this period. This argument was supported by the distribution of the average TFP by five-year intervals over twenty years as shown in Table 3.

Figure 1: Total Factor Productivity and its component: 1986-87 to 2014-15



Source: Authors' drawing using data from Table 2 of the above

From Table 3, it is clear that the highest value of the average TFP-growth (1.18) was associated with the period 1991-95. Similarly, the largest average TC value (1.17) was associated with the same period, whereas the average value of TE was one (1.00) during this period. This finding implies that the TFP-growth was mostly influenced by TC in this period. On the other hand, during 1996-2000 the growth in TFP was mostly weighted by the influence of TE, not by TC because the average value of TE (1.04) was greater than one but the average value of TC (0.96) was smaller than one. This analysis suggests that the TFP-growth of rice production was mostly influenced by technological change in the post-liberalisation period.

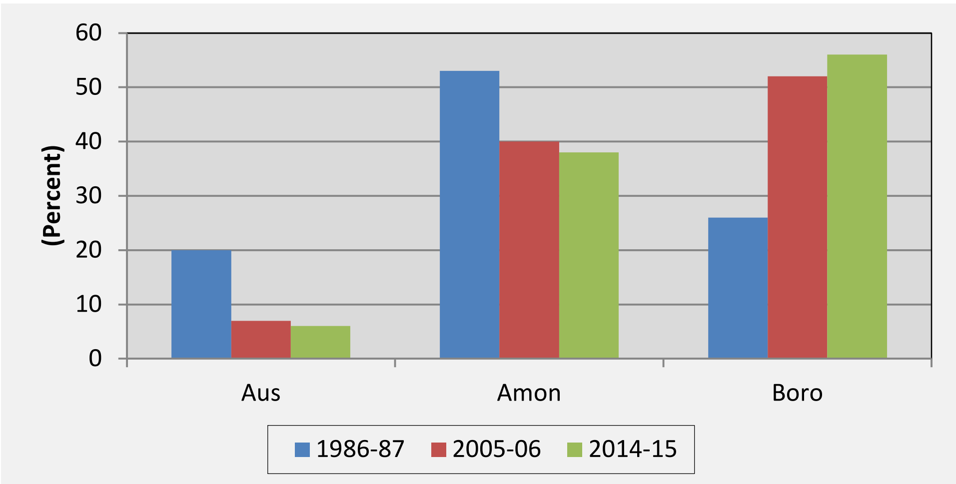
Table 3: Distribution of average TFP by five-year intervals: 1986-2015

Year	Total Factor Productivity (TFP)	Technical Efficiency (TE)	Technological Change (TC)
1986-90	0.94	0.95	0.99
1991-95	1.18	1.00	1.17
1996-00	1.13	1.05	1.04
2001-05	0.87	0.99	0.87
2006-10	0.84	0.97	0.85
2011-15	0.82	0.88	0.83

Source: Authors' calculation from Table 2 of the above

The change in the TFP-growth of rice might be attributed to the shift of rice cultivation from local varieties to HYV rice and from Aus and Amon to Boro cultivation as a result of the technological transformation in rice production. This situation is revealed in Figure 2. Boro rice captured the lager share and the shares of both Aus and Amon rice production gradually declined during 1986-87-2014-15.

Figure 2: Share of production by major rice crops: 1986-87-2014-15



Source: Authors' calculation from Table 2.01 and 1.03 (Ministry of Agriculture, 2007) and (Ministry of Finance, 2017)

This analysis suggests that the TFP of rice increased immediately after agricultural trade liberalisation due to adoption of new technology, namely fertilisers-irrigation-HYV rice. Amongst these three inputs, irrigation had the greatest influence on productivity of rice because it is the prime input that influenced reallocation of resources (land, labour etc.) in favour of Boro rice cultivation and increased cropping intensity in the early stage of post-liberalisation era.

This is an indication that TFP-growth of rice was driven by the Boro crop, which is dominated by HYV rice. Amongst the three rice crops (Aus, Amon and Boro), Boro is cultivated during the dry seasons (winter and spring), when water is available for irrigation. Farmers can control irrigation and apply fertilisers and pesticides on time, resulting in higher yields. Aus is cultivated during the dry season (summer) but water is not available for irrigation, resulting in lower yields. Conversely, Amon is cultivated during the wet (rainy) season, when farmers have little control over rainwater. Therefore, there are two main reasons for reallocation of land to Boro crop: (1) Boro is the most productive rice crop in the post-liberalisation era; and 2) the majority of farm households are subsistent and small farmers, who are poor and are much more interested in producing rice as a staple food than producing other food-grains and cash crops, leading to reallocation of resources in favour of the most productive Boro rice.

The significant increase in Boro rice production was possible because of the wider availability of small-scale imported irrigation equipment such as shallow tube-wells and low lift pumps as well as other inputs such as fertilisers and HYV seeds following agricultural trade liberalisation.

Although Bangladesh experienced a significant increase in TFP-growth in rice production immediately after agricultural trade liberalisation, this trend was sustained for only one decade and the impact of this technology on the productivity of rice gradually slowed down. This decline might be attributed to technological non-progress as technology gradually becomes obsolete after its adoption if innovation, and research and development (R&D) are not sufficient to replace the old technology, suggesting that technological innovation in rice production through R&D is required to increase total factor productivity growth of rice in future. This productivity growth in the post-liberalisation era is much attributed to the shift of cropping patterns in favour of more productive HYV rice and specially Boro crops. Amongst all inputs, HYV seeds and irrigation are dominant contributors to this growth and the increase in the volume of rice production over last two decades. The regression analysis presented in the following section reinforces this argument.

5.3. Input Oriented Regression Analysis

The study carried out a factor-oriented (input) regression analysis and estimated the Cobb-Douglas production function with a view to identifying the impact of individual inputs or factors on total rice production. The factors of production considered in these models were land, labour, irrigation, fertilisers, pesticides and seeds. However, some factors including land, pesticides and seeds were not statistically significant. Therefore, they were excluded from the model because including them does not significantly improve the model's fit. The seeds factor was not statistically significant. The results are shown in Table 4.

The regression coefficient for irrigation was the largest contributor to rice production with a regression coefficient of 1.342 in the post-liberalisation period. The other two factors – labour and fertilisers – were statistically significant but both factors had negative regression coefficients of –0.336 and –0.643 respectively. This study suggests that there is an inverse relationship between total rice output and labour as well as between total rice output and fertilisers. This is because excess labour is employed in rice production in Bangladesh. The productivity of labour is negative. This correlation suggests that over time rice output is rising and the requirement of labour allocated to rice farming is falling as farmers adopt new technologies and shift to a more capital intensive production process and higher yielding rice. One reason for the persistence of excess labour in the agricultural sector is the weakness of the country's public education sector, which limits severely the growth of non-agricultural employment. This model suggests that excess labour employed in rice production constitutes wastage of resources in the rural economy and that might be better used for other productive activities. Therefore, removal of excess labour from rice production would likely increase productivity of labour for rice output. Similarly, the negative impact of fertilisers on total rice production might be attributed to the inappropriate application of cheap fertilisers to rice cultivation in the post-liberalisation period.

Irrigation had a very large and positive regression coefficient (1.342), indicating that an increase in one unit of irrigation was likely to increase the total rice production by 1.342 units, suggesting that rice productivity was driven by irrigation-related crops (mainly HYV-Boro) in the post liberalisation era. This finding has significant implications that irrigation-oriented technology was dominant factor in determining the productivity of rice in the post-liberalisation period.

Table 4: Determinants of output by factors of production: 1986-87 to 2014-15

(**Dependent variable:** Logarithm of total rice production)

Independent variables	Regression coefficient	Correlation coefficient
Constant	10.08 (1.83)***	
Log of total land area	excluded, not significant	
Log of total irrigated area	1.34 (0.21)***	0.92
Log of total fertiliser use	-0.64 (0.23)*	0.83
Log of total pesticide use	excluded, not significant	
Log of total labour employed	-0.33 (0.01)**	-0.89
Log of total seeds use	excluded, not significant	
	R-square: 0.96 df1: 3, df2: 16 F: 128.570, P: .000	

Note: time series data used, number of observations are 20 (20 years' data between 1986-87 and 2005-06)

excluded variables are not statistically significant
figures in parentheses represent standard errors
*** significant at 1%, ** significant at 5% and * significant at 10% level

6. Conclusion

The above findings and analyses suggest that agricultural trade liberalisation positively influenced productivity of rice as a result of technological transformation in rice production. The economy experienced an increase in TFP-growth driven by technological change in the post-liberalisation era. The TFP-growth is a multiplicative impact of technical efficiency change and technological change generated from the efficient use of inputs and an outward shift in production possibility frontier respectively. The improvement in productivity of rice contributed to a higher volume of rice output. The increase in productivity and total output was driven by cropping shifts from local varieties to the HYV rice and reallocation of resources in favour of the HYV-dominated Boro rice in the post-liberalisation era. The use of irrigation, fertilisers, pesticides, and HYV seeds increased in the post-liberalisation era because of lower input prices, resulting from agricultural trade liberalisation.

The study found that the impact of technological change on the TFP-growth gradually slowed down after the first decade of high growth in productivity of rice. This slow-down in TFP-growth might be attributed to technological non-progress as technology gradually becomes obsolete after its adoption if innovation, and research and development (R&D) are not sufficient to replace the old technology. The study suggests that R&D development activities are required to strengthen technological innovation for improving technological change in rice production to achieve and sustain higher TFP-growth in the future. Similarly, there is a huge amount of excess labour employed in rice production. This excess labour may be reallocated to other sectors for increasing productivity of labour in rice output and will contribute to higher household income from economic activities other than rice production. The intensive and efficient use of factors is crucial for increasing technical efficiency in rice production that will contribute to the total factor productivity growth as well. Therefore, the study suggests that the government should formulate policies to increase investment in (1) research and development for technological innovation, and (2) in human resource development through training and extension services for efficient use of inputs to improve TFP-growth in rice production. This policy would enhance food production for a large population and ensure food security and macroeconomic price stability that might come from high food prices.

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