Three Essays on Agricultural Productivity, Convergence, and Causality

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Abul Bashar Md Rahmatullah

Graduate School Of Systems and Information Engineering

University of Tsukuba

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Abstract

This thesis addresses three current issues on agriculture: regional productivity, convergence in productivity, and policies to increase the growth in productivity. We use two different data sets to estimate the pattern of productivity growth in agriculture across districts, long-run movement in the regional productivity differences, and causal linkages between productivity and capital investment. Once we found that regional inequalities prevails in agriculture across districts, then we studies to check either convergence or divergence occurs in productivity in the long-run. Further, we examines on the possible reasons of productivity declining and attempt to explain what policies we should adopt to increase productivity growth.

Chapter 2 estimates the Malmquist productivity index, technical change index, and technical efficiency change index. These are reported for a multiple output- multiple input production technology for Bangladesh agriculture at the district level from 1979 to 1999 by using non-parametric approach. This chapter further attempts to identify the most and least technologically developed, and innovative districts. This study finds that the modern technology has helped in increasing the productivity which is largely contributed by the growth in technical change, and we further failed to identify any district as the sole innovator who contributed to shift the frontier in Bangladesh agriculture. The results suggest that the knowledge on the technology has not been spread equally among all the districts in Bangladesh.

Extending the previous analysis in Chapter 3, we addresses the issue of convergence in agricultural productivity among districts in Bangladesh. We employed

cross-section convergence tests, β and σ convergence, and panel unit root convergence test. The estimated coefficient of the initial productivity level is negative and significant in β convergence test indicating convergence in agricultural productivity. The result of σ convergence test shows that there has been a decrease in the cross-districts dispersion of productivity in agriculture over the entire time period. The panel unit root test further support the conventional test, and therefore, we may conclude that dispersion of productivity is stationary providing strong evidence that the districts do exhibit long-run convergence.

We analyze an equally important issue on how to improve the agricultural productivity growth which is discussed in Chapter 4. As various literature suggest that productivity growth is associated with capital investment, and from the policy perspective it is important to know how and in which direction the capital investment influence the productivity growth. Therefore, we investigate the long-run relationship between productivity and capital investment to confirm the learning-by-doing process.

Although we can not ignore the importance of capital in agriculture, however, the data on capital in Bangladesh agriculture is not available. As we discussed in Chapter 2, in the absence of capital data we choose irrigation and fertilizer as a proxy of capital to estimate productivity in Bangladesh agriculture. Due to unavailability of data on capital, we conducted this study on Japanese agriculture to check the causal linkages between productivity and capital. The findings in this chapter will directly help to take appropriate steps to improve productivity growth in Japanese agriculture, and these results will provide a guideline to the policy makers in Bangladesh to adopt the correct measures to boost the productivity.

We employ the Granger causality test to determine the causality between the two variables. This study also investigates movements in total output, total input, and TFP for average farms of four size classes for the period 1957-97. We employ the aggregation technique to estimate total output and total input, and use a large pooled cross-section and time series data set. It has been found that both TFP and capital investment had a fairly high growth rate from the mid 1950s to the early 1970s, and thereafter it started declining. The result of this study shows that there is a significant and positive bi-directional Granger causal relationship between TFP and capital investment in Japanese agriculture over the long term.

Several important polices are drawn from this study which are described in Chapter 5. This thesis supports the policies to address the cause of the drastic fall in efficiency in Bangladesh agriculture, suggests large scale farming, and an increase in the volume of capital investment in order to increase total output and productivity.

Overall, the empirical results of this thesis is in line with the contention of the current issues on agricultural productivity, and supports the policies for the balanced regional growth and overall growth in productivity.

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My family members have been a source of inspiration and endless encouragement. I dedicate this work to all of them ----- I love you all.

Chapter 1

Introduction

1.1 Initial Comments

After introduction of the 'Green Revolution' technology the agricultural sector has contributed significantly in the growth and stability in most parts of Asia from the late 1960s. Either directly or indirectly it has served the livelihood to a significant portion of the population.

However, the trends over the last two decades show that the contribution of agriculture in the overall growth of the economy is declining. The reason for such declining might be because of several factors, such as technological regression, gap between the productive and less productive countries or regions, less demand for agricultural commodities.

For the sustainability in agricultural production, we need to have information on the relative position of different countries or regions in terms of agricultural productivity, we need to reduce the regional disparities if any, and it is important to study the causal relationship between productivity and the variables that explain productivity growth.

This thesis is made up of three essays that address the above issues. In Chapter 2 and Chapter 3, topics related to regional productivity growth, and long-run movement in the regional productivity differences are discussed in the context of Bangladesh agriculture. In Chapter 4, we have studied the Japanese agricultural productivity, and investigated the causal relationship between productivity and capital investment.

In Section 1.2 of this chapter, we outline the motivation for the studies undertaken in this thesis. Section 1.3 summarizes the earlier studies related to this thesis. In Section 1.4, we discuss the method of analysis, then summarize our results, and highlight the contribution of this thesis. In Section 1.5, we explain the organization of the thesis.

1.2 Motivation for the Thesis

The agricultural sector in Bangladesh is considered as the most important sector since it generates income and provides employment to a larger portion of the population. Although this sector continues in contributing to the economy, but its share is decreasing and the growth rate has slowed down. The other major concern is regional variations in the growth of production. There is a high magnitude of disparities between the districts in productivity growth.

Previous studies focused on the aggregated national level to measure productivity, and addressed the issues on crop diversification, linking growth of productivity to the theory of production, and agricultural extension policies. However, there were few attempts on the district level productivity measurement, and identifying the most (or least) innovative and efficient districts. It should be mentioned that the information on the relative position of the districts is a must to reduce the existing inequality among the districts and to sustain a steady growth in agriculture.

In the context of the above discussion, therefore, we are motivated to study the productivity of the different districts of the agricultural sector of Bangladesh for the period 1979-99, and attempt to identify the leading districts in technological knowledge and efficiency. In addition, this study tries to test the convergence or divergence of productivity among the different agricultural districts.

Another point of interest in our study is to improve the level of agricultural productivity growth, therefore, we need to check the long-run relationship between productivity and the variables that explain productivity. In Bangladesh agriculture, it has been found that the production of food grains increased due to an increase in capital rather than an increase in labor. Therefore, we cannot ignore the importance of capital in agricultural productivity. From the policy perspective, it is important to know how and in which direction the volume of capital investment will lead to productivity. However, the time series data for capital use in agricultural production at district level are not available.

Literature on Japanese rice production suggest that the productivity growth associated with capital investment in the long-run. A closer look in the overall Japanese agriculture shows that the simultaneous increasing, and decreasing of both capital investment and productivity growth rates during the last four decades has raised a question on the causal relations between them. The rich data set on Japanese agriculture encourages us to study the influence of capital on the overall agricultural productivity.

The motivation for the study on Japanese agriculture is twofold. In one hand, this study will suggest what measures should the policy makers adopt to increase total productivity in Japanese agriculture. And, on the other hand, the findings from this study may help as a guideline to the policy makers in Bangladesh to take appropriate steps to boost the productivity growth.

A question may arise whether the condition under which the capital influences the productivity growth in Japanese agriculture also applies to Bangladesh agriculture. It is true that the structural environment is different in every country. Keeping these differences in mind, there is a large volume of literature on inter-countries' agricultural sector. We have also found that the findings, and suggestions of such studies are applied to many countries irrespective of the volume and structure of the economy. Therefore, we are assured that similarly the findings in Japanese agriculture will also help to a certain extent to Bangladesh agriculture.

A closer look at the earlier studies in these areas is necessary to put this thesis into perspective. In the following Section 1.3, we provide an overview of the existing research relevant to this thesis.

1.3 Background of the thesis

One of the main objectives of this thesis is to estimate the agricultural productivity. Thus, in the first essay of this study, we use the non-parametric approach to estimate the Malmquist productivity index in Bangladesh agriculture at the district level. Previous studies applied partial productivity, Törnqvist-Theil index, or traditional econometric approaches to estimate productivity at aggregated national level. There have been numerous studies on the Malmquist productivity analysis for cross-country or inter-regional levels. However, to the best of our knowledge, there are very few studies that have constructed productivity indexes using this modern technique at district level in Bangladesh.

Further, there has been no study to identify the most innovative and technical efficient districts in Bangladesh. To evaluate the district level disparities, we attempted to identify the districts which shifted the frontier over time and played the role as innovators.

The findings in the first essay lead us to test convergence of productivity to check if there is narrowing down of productivity gaps among districts over a certain period of time. Alternatively, it determines if less developed districts are catching up to developed districts in terms of productivity. This issue is discussed in the second essay.

Unlike in many countries, there are very few studies on convergence in Bangladesh. The issue on convergence is very crucial in Bangladesh context. From a policy perspective, it is desirable to achieve a potential reduction in regional inequality in agricultural productivity in the long-run. For a balanced regional development and sustainability in agricultural production, it is needed to undertake studies on convergence and take effective measures to reduce inequalities.

To confirm the learning-by-doing process which postulate that a level of technical knowledge is approximated by an accumulated level of the capital, and that the knowledge spills over an entire economy, and to check in which direction capital influences the changes in productivity, we need to study the linkages between productivity and capital. Due to unavailability of data on capital at district level in Bangladesh, we conducted this study on Japanese agriculture. This issue is discussed in the third essay.

Previous studies on Japanese agriculture discussed the estimation and decompositions of productivity, biased technological change, factor demand in postwar agriculture, etc. However, they failed to address the causal linkages between productivity and the variables that explain productivity, mainly capital investment.

To sum up, this thesis attempt to measure the regional productivity growth, test convergence of productivity among districts, and provides a guideline on what should be the appropriate measures to increase the productivity growth.

In the next section, we explain the framework for analysis to empirically estimate agricultural productivity, convergence, and causality between productivity and capital investment.

1.4 Analytical Procedure in the Thesis

In the light of the above discussion, here, we formulate our research plan below. The topics for the discussion are of current interest and relevance to agricultural productivity.

1.4.1 Research Topics

In the context of the motivation and the background of the study mentioned above, we summarize questions to be addressed in this study as follows:

i) What has been the pattern of productivity growth in agriculture across the different districts of Bangladesh? Are there any districts which can be considered as the sole innovator or contributed to shift the frontier in Bangladesh agriculture?

ii) Is the diffusion of technology leading to convergence or divergence in productivity across districts in Bangladesh?

iii) Why Japanese agriculture slowed down after the rapid growth? Are there any causal links between productivity and capital investment?

1.4.2 Data Sources

For this thesis we used two different data sets. The data set for the study on Bangladesh agriculture was collected from various issues of Statistical Yearbook of Bangladesh, and Yearbook of Agricultural Statistics of Bangladesh which are published by the Ministry of Planning; An Agricultural Statistical Profile of Bangladesh published by the CGPRT center; and various studies undertaken from time to time. The data set employed in this study is a panel of twenty districts for the period 1979 to 1999.

For the study on causality we have collected the data set from the Survey Report on Farm Household Economy (FHE) and the Survey Report on Prices and Wages in Rural Villages (PWRV), published annually by the Ministry of Agriculture, Forestry, and Fisheries (Japan). In each year of the 1957-97 period, one average farm was taken from each of the four size classes, 0.5-1.0 (I), 1.0-1.05 (II), 1.5-2.0 (III), and 2.0 hectares and larger (IV), from all Japan (excluding Hokkaido prefecture because of the different size classification).

1.4.3 Result and Contribution

i) We have measured the Malmquist productivity index and found that the average annual growth in productivity was mainly contributed by the growth in technical change rather than improvements in technical efficiency. The growth rate varies among the districts, and we did not find any district which can be considered as the sole innovator or contributed to shift the frontier in Bangladesh agriculture. For the period analyzed, the knowledge of technology has not been spread equally among all the districts. This is the first study of its kind for Bangladesh.

ii) Our cross-section and time-series convergence test confirms that divergence among districts disappear and agricultural productivity reach convergence in the long-run. This is one of the first studies of its kind for Bangladesh, and is in line with evidence from India and China.

iii) The results of the causality tests suggest that there has been a significant and positive Granger causal relationship running from TFP to capital as well as from capital to TFP in Japanese agriculture over the long term. The findings are in line with evidence on Japanese rice production.

1.5 Organization of the Thesis

As we discussed earlier, the objectives of this study is three fold. They are: to study the productivity of the different districts of the agricultural sector, to test the convergence or divergence of productivity among the different agricultural districts, and to check the long-run relationship between capital and productivity. These issues are discussed in three essays in this thesis.

Chapter 2 focuses on the first essay "Regional Productivity in Bangladesh Agriculture, 1979-1999". In this essay, we estimate the Malmquist productivity index, and then decomposed the index into technological change index, and technical efficiency change index for the twenty districts. We further identify the innovative and technically efficient districts, and attempt to make a list of model districts who may play a role on the balanced growth among all the districts.

This study estimated the mixed productivity growth rates among the districts and it confirms that the modern technology has not been spread equally among all the districts during the study period. The outcomes in this essay lead us to study the long-run movement in the district level productivity differences which is discussed in the second essay.

Our second essay on "Convergence in Bangladesh Agriculture" is presented in Chapter 3. In this study, we analyze the question of productivity convergence among the Bangladeshi districts. Our results indicate both the cross-sectional convergence tests, σ and β convergence, as well as the panel unit root test found convergence in the growth of district level productivity.

From a policy perspective, this is a positive achievement as it implies potential reduction in regional inequality in agricultural productivity in the long-run. Another objective in this study is how to increase the productivity level. As we have seen that capital influences in the production of the food grains in Bangladesh agriculture, and productivity growth is associated with capital investment in Japanese rice production, therefore, we are interested to check the causal linkages between capital investment and productivity. This issue is discussed in the third essay of this thesis.

In Chapter 4, we introduce our third essay on "Causality between Capital Investment and Productivity in Japanese Agriculture, 1957-1997". In this essay, we measured productivity indexes for the four size classes by using the multilateral index proposed by Caves, Christensen and Diewert (1982). The Granger causality test was used to determine the causality between productivity and capital investment. The results suggested that there is a significant and positive causal relation between the two variables over the long-run.

Chapter 5 concludes this thesis with a summary of the findings and policy implications.

Chapter 2

Regional Productivity in Bangladesh Agriculture, 1979-1999

2.1 Introduction

Agriculture has played an important role in the growth and stability of the economy of Bangladesh, accounting for about 25% of GDP and nearly 70% of employment (BBS, 2000). Although the share of agriculture in GDP appears to be declining[1], agriculture will remain the largest single contributor to the economy in the years to come.

As we have found in various past studies, the modern technology has helped to increase the productivity. However, the knowledge on the technology has not been spread equally among all the districts to remove the district level disparities. The knowledge on district level disparities is very desirable for the government to take appropriate steps for balanced growth among the districts and to identify appropriate strategies of development.

In a district level context, it seems very important for Bangladesh to know the relative position of different districts in terms of agricultural productivity and to identify the technologically innovative or inefficient districts, so that the government can plan for a balanced growth among all the districts.

As seen in the next section, there have been numerous studies on Bangladesh agriculture. The major focuses have been on: measuring TFP, decomposition of TFP,

[1] Please Refer to Appendix II (Table A1).

agricultural growth through crop diversification, food production sustainability, linking the growth of TFP to the theory of production, technological change and factor demand in Bangladesh agriculture.

Although there have been plenty of studies on the measurement of agricultural productivity for Bangladesh at aggregated national level, but we have found that there have been few attempts to study in the district level productivity growth and to identify the technologically innovative districts. Thus, this study attempts to estimate the productivity[2] growth, technological change, and technical efficiency change among the major twenty districts[3] in Bangladesh.

Most of the previous studies on Bangladesh agricultural productivity are very similar in terms of objectives and methodologies used[4]. The earlier studies have applied either partial productivity or total factor productivity using index number approaches such as Törnqvist-Theil index or traditional econometric approaches. Moreover, the estimations in the earlier studies were based on average practice production functions rather than the best practice technology. Therefore, such studies assumed that producers are efficient, which may be unreasonable in the context of Bangladesh.

This study estimates productivity, technical change, and technical efficiency change indexes. They are reported for a multiple output-multiple input production technology for Bangladesh agriculture at district level from 1979 to 1999 by using a non-

[2] In this study we use the term productivity, total factor productivity (TFP), and multi factor productivity (MFP) interchangeably.

[3] The districts are: Dinajpur, Rangpur, Bogra, Rajshahi, Pabna, Kushtia, Jessore, Khulna, Barisal, Patuakhali, Mymensingh, Jamalpur, Tangail, Dhaka, Faridpur, Sylhet, Comilla, Noakhali, Chittagong, and Chittagong Hill Tracks.

[4] According to Suhariyanto et al. (2001), studies on Asian agriculture (including Bangladesh) are out of date in terms of period studied and methodology used.

parametric approach. This study applies the Malmquist-based productivity measures, which was developed by Färe et al. (1994), to Bangladesh agriculture at district level.

This paper differs from the past research in several ways. It is one of the first papers to use the Malmquist productivity index at the district level in Bangladesh agriculture, and to attempt to identify the most and least innovative districts, and the districts which shifts the frontier. Accordingly, the first objective of this paper is to measure and compare the TFP growth in different districts of Bangladesh and to decompose of the TFP index into technical change and technical efficiency indexes. The second objective is to identify the innovative and technically efficient districts and their role on the balanced growth among all the districts.

The rest of this paper is organized as follows: Section 2.2 provides a survey of the literature concerning productivity in Bangladesh agriculture and the use of Malmquist index to measure the productivity. Section 2.3 deals with the methodology for productivity measurement, decomposition of productivity, and identification of the most and least innovative districts. Section 2.4 describes the sources and definitions of the variables and the data used in this study. Section 2.5 contains the empirical results and analysis. Finally, conclusions are drawn in Section 2.6.

2.2 Literature Review

This study is on the district level productivity analysis for Bangladesh agriculture and attempts to identify the advanced or backward districts, and to suggest measures for removing the regional disparities among the districts for a balanced growth. We use the

Malmquist productivity index procedures for this study. The review of the literature focuses on two topics: Bangladesh agricultural productivity in general and the Malmquist productivity index.

At first, the theoretical background on these two topics will be investigated and then we will look at previous researches done on these topics. An overview on both topics is followed in the following sub-sections.

2.2.1 An Overview of Bangladesh Agriculture

A number of studies on measuring and analyzing productivity in Bangladesh agriculture have been carried out by Jahan and Alauddin (1996), Rahman (1999, 2005), Sarker and Islam (1999), Ahmed (2001), to name only a few.

Pray (1985), Pray and Ahmed (1986, 1991), Dey and Evenson (1991) estimated total factor productivity in Bangladesh agriculture by considering total output and total conventional input. Jahan and Alauddin (1996) followed Törnqvist-Theil index procedure to construct the TFP index and later decomposed the index into various factors.

Rahman (1999) found that although technological change played a significant role in augmenting aggregate crop productivity, but the declining productivity of modern rice raised doubts on sustaining food production. Mahmud (1998), in his essay on agricultural development strategy, argued that the current cropping patterns evidently offer little scope for crop diversification through expansion of modern irrigation.

McIntire (1998) explained that the impact of education is stronger in a modernizing environment, suggesting that lack of education may be one reason why

Bangladesh agriculture is not able to fully exploit available technologies. According to Siddiqui (1998), an important role is to enable farmers to identify and resolve local agricultural problems and any agricultural extension program need to be aware of local availability of agricultural inputs.

We have found that a substantial number of studies on Bangladesh agriculture have been carried out by many researchers. Their work focused on the measurement and decomposition of TFP, agricultural growth through crop diversification, food production sustainability, linking the growth of TFP to the theory of production, technological change and factor demand in Bangladesh agriculture, etcetera. However, we have found that there have been few attempts to study on the district level productivity growth and to identify the technologically innovative districts. Moreover, most of the previous studies on Bangladesh agricultural productivity are almost the same in terms of objectives and methodology used.

2.2.2 The Malmquist Productivity Index

The Malmquist productivity index was developed by Caves et al. (1982) and later Färe et al. (1994) showed how this index can be constructed by using non-parametric linear programming techniques of data envelopment analysis to fit distance functions. Since then there have been many studies which used this technique for cross-country or inter-regional levels to construct the TFP indexes.

The notable works on the construction of Malmquist TFP index are: Färe et al. (1994) on 17 OECD countries, Bureau et al. (1995) on nine European Union countries and the United States, Lambert and Parker (1998) on Chinese provincial agriculture, Millan and Aldaz (1998) on the Spanish regions, Thirtle et al. (2003) on Botswana, Horie and Yamaguchi (2003) on Japanese agriculture, Suhariyanto and Kuroda (2002) on OECD countries, and Alauddin et al. (2004) on 111 countries, to name only a few.

The advantages of the Malmquist productivity index is listed in Färe et al. (1994), Thirtle et al. (1995), Grifell-Tatjé and Lovell (1996, 1997), Lambert and Parker (1998), Coelli et al. (2000), and others. Here we look at the positive features of the Malmquist index which are listed in the above-mentioned studies.

Firstly, the Malmquist index is non-parametric, therefore, this index does not require any specification of the functional form of the production technology. Secondly, this technique does not require an economic behavioral assumption of production units such as cost minimization or revenue maximization. Thirdly, productivity can be estimated with multiple outputs as well as multiple inputs. Fourthly, we do not have to rely on price data to construct the index. Fifthly, constant shares are not imposed on inputs or outputs to estimate the index. And finally, the index decomposes productivity change into technical efficiency change and technical change.

Let us take these desirable features of the Malmquist index in mind. As we have found that the economic behavior of the production units in agriculture is uncertain and the consistent price data on all the variables are not available for the Bangladesh agriculture at district level, the choice of the Malmquist index for this study is well justified.

2.3 Research Methodology

The analysis presented in this study is basically divided into two major parts. The first part will deal with the measurement of Malmquist productivity index at the district level in Bangladesh agriculture, and decomposition of TFP into technical change and technical efficiency change indexes. The second part will attempt to identify the most and least technologically developed and efficient districts, and the districts which shift the frontier in Bangladesh agriculture.

2.3.1 Measurement of the Malmquist Productivity Index and Its Components

This study uses the Malmquist TFP index, which is presented in Caves et al. (1982) and Färe et al. (1994), to measure the TFP change between the two data points by calculating the ratio of the distances of each data point relative to a common technology. The Malmquist TFP index can be defined using either the input-oriented approach or the output-oriented approach.

An input distance function characterizes the production technology by looking at a minimal proportional contraction of the input vector, given an output vector. An output distance function considers a maximal proportional expansion of the output vector, given an input vector (Coelli et al., 2000).

In this study, we will use the output distance function to estimate the Malmquist TFP index. To estimate the output-based Malmquist TFP index, we need to define a production technology.

We may define the production technology using the output set, $Q(x)$, which represents the vector of the set of all outputs, y, which can be produce using the input vector, x. Then we may write as,[5]

$$Q(x) = \{y: x \text{ can produce } y\} \tag{2.1}$$

We assume that this set satisfies all the properties[6] mentioned in Coelli et al. (2000, pp 62).

Now we may define the output distance function on the output set as, $Q(x)$, as

$$d_o(x,y) = \min_\theta \left\{\frac{y}{\theta} \in Q(x)\right\} \tag{2.2}$$

From the equations (2.1) and (2.2), we may conclude that if the output vector, y, is an element of the feasible production set, $Q(x)$, then the distance function, $d_o(x,y)$, will be less than or equal to 1. On the other hand, if the output vector, y, is found on the outer boundary of $Q(x)$, then the value of the distance function will be equal to 1. And, if the output vector is situated outside of $Q(x)$, then the value of distance function will be greater than 1.

As we have already mentioned that the Malmquist TFP index measures the productivity change between the two data points, following Färe et al. (1994) the output-based Malmquist index between period t and $t+1$ is defined as:

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[5] The formulation draws heavily on Coelli et al. (2000, ch: 10).

[6] The properties of this set are summarized as follows. For each x, the output set $Q(x)$ is assumed to satisfy: (i) $0 \in Q(x)$: nothing can be produced out of a given set of inputs, (ii) non-zero output levels cannot be produced from zero level of inputs, (iii) $Q(x)$ satisfies strong disposability of outputs: if $y \in Q(x)$ and $y^* \leqslant y$ then $y^* \in Q(x)$, (iv) $Q(x)$ satisfies strong disposability of inputs: if y can be produced from x, then y can be produced from any $x^* \geqslant x$, (v) $Q(x)$ is closed, bounded and convex.

$$m_o(y_t, x_t, y_{t+1}, x_{t+1}) = \left[\left(\frac{d_o^t(y_{t+1}, x_{t+1})}{d_o^t(y_t, x_t)} \right) \times \left(\frac{d_o^{t+1}(y_{t+1}, x_{t+1})}{d_o^{t+1}(y_t, x_t)} \right) \right]^{1/2} \quad (2.3)$$

In equation (2.3), $d_o^t(y_{t+1}, x_{t+1})$ represents the distance function from the period $t+1$ observation to the period t technology. The TFP growth from period t to period $t+1$ will be positive if the value of m_o is greater than one. On the other hand, if m_o is less than one, then it indicates a decline in the TFP growth.

Equation (2.3) shows us that the productivity change is measured as the geometric mean of the two TFP indexes. The first part on the right hand side of the equation is given for the period t technology and the second part is evaluated for the period $t+1$ technology.

One of the major advantages of the Malmquist productivity index is that it can be decomposed into technical efficiency change and technological change. Therefore, in an equivalent way, we may rewrite the Malmquist productivity index such as:

$$m_o(y_t, y_{t+1}, x_t, x_{t+1}) = \frac{d_o^{t+1}(y_{t+1}, x_{t+1})}{d_o^t(y_t, x_t)} \left[\left(\frac{d_o^t(y_{t+1}, x_{t+1})}{d_o^{t+1}(y_{t+1}, x_{t+1})} \right) \times \left(\frac{d_o^t(y_t, x_t)}{d_o^{t+1}(y_t, x_t)} \right) \right]^{1/2} \quad (2.4)$$

Equation (2.4) provides the decomposition of the Malmquist TFP index[7]. The change in technical efficiency[8] between period t and $t+1$ is captured by the ratio outside the brackets on the right hand side. The ratio within the brackets measures the technical change[9] between period t and $t+1$.

Therefore, the productivity growth is defined as the product of technical efficiency change and technological change. And, we may write it as:

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[7] Please refer to Appendix I for a graphical presentation of Malmquist productivity index.
[8] Technical efficiency measures how much closer a district gets to the country's frontier.
[9] Technical change measures how much the country's frontier shifts at each district's observed input mix.

Malmquist Index = Technical Efficiency Change (TEC) x Technological Change (TC)

The technical efficiency change (TEC) component is greater than, equal to, or less than one according to whether technical efficiency improves, remains unchanged, or declines between period t and $t+1$. Similarly, technical change (TC) component is also greater than, equal to, or less than unity, and it shows whether the frontier is improving, stagnant, or deteriorating.

The value of the TEC and TC determines the value of the Malmquist index, which may also be greater than, equal to, or less than unity. We will have improved productivity if the value of the index is greater than unity.

There are various methods which can be used to estimate the distance function to construct the Malmquist TFP index. In this study, we calculate the distance by using Data Envelopment Analysis (DEA) technique under the constant returns to scale (CRS) assumption to measure the Malmquist index. The input oriented and CRS model was proposed by Charnes, Cooper, and Rhodes (CCR, 1978). The CRS assumption is appropriate when all firms are operating at an optimal scale. Banker, Charnes, and Cooper (BCC, 1984) suggested an extension of the CRS DEA model to account for variable returns to scale (VRS) situation.

One issue that must be stressed is that the returns to scale properties of the technology is very important in TFP measurement. Grifell-Tatjé and Lovell (1995) use a simple one-input, one-output example to illustrate that a Malmquist TFP index may not correctly measure TFP changes when variable returns to scale is assumed for the technology. Hence, it is important that constant returns to scale be imposed upon any technology that is used to estimate distance functions for the calculation of a Malmquist

TFP index. Otherwise, the resulting measures may not properly reflect the TFP gains or losses resulting from scale effects (Coelli et al., 2000, ch: 10).

To measure the TFP change between the two periods (t and $t+1$) for the *i-th* district, we need to calculate four distance functions. Therefore, we need to solve four linear programming (LP) problems. According to Färe et al. (1994) which assumed a constant return to scale technology, the required four LPs are:

$$\left[d_o^{t+1}\left(y_{t+1}, x_{t+1}\right)\right]^{-1} = \max_{\phi,\lambda} \phi,$$

$$\text{st} \quad -\phi y_{i,t+1} + Y_{t+1}\lambda \geq 0,$$

$$x_{i,t+1} - X_{t+1}\lambda \geq 0, \tag{2.5}$$

$$\lambda \geq 0,$$

$$\left[d_o^{t}\left(y_{t}, x_{t}\right)\right]^{-1} = \max_{\phi,\lambda} \phi,$$

$$\text{st} \quad -\phi y_{i,t} + Y_{t}\lambda \geq 0,$$

$$x_{i,t} - X_{t}\lambda \geq 0, \tag{2.6}$$

$$\lambda \geq 0,$$

$$\left[d_o^{t+1}\left(y_{t}, x_{t}\right)\right]^{-1} = \max_{\phi,\lambda} \phi,$$

$$\text{st} \quad -\phi y_{i,t} + Y_{t+1}\lambda \geq 0,$$

$$x_{i,t} - X_{t+1}\lambda \geq 0, \tag{2.7}$$

$$\lambda \geq 0,$$

and

$$\left[d_o^{t}\left(y_{t+1}, x_{t+1}\right)\right]^{-1} = \max_{\phi,\lambda} \phi,$$

$$\text{st} \quad -\phi y_{i,t+1} + Y_t\lambda \geq 0,$$

$$x_{i,t+1} - X_t\lambda \geq 0, \tag{2.8}$$

$$\lambda \geq 0,$$

where $y_{i,t+1}$ is a $M \times 1$ vector of the output quantities for the $i-th$ district in the $t+1-th$ period; $x_{i,t+1}$ is a $K \times 1$ vector of the input quantities for the $i-th$ district in the $t+1-th$ period; Y_{t+1} is a $N \times M$ matrix of the output quantities for all N districts in the $t+1-th$ period; X_{t+1} is a $N \times K$ matrix of the input quantities for all N districts in the $t+1-th$ period; λ is a $N \times 1$ vector of weights; and ϕ is a scalar, reflecting the degree to which the output vector can be expanded or contracted.

In equations (2.7) and (2.8), production points are compared to technologies from different time periods, the ϕ parameter need not be greater than or equal to one. The data point could lie above the production frontier. This will most likely occur in equation (2.8), where a production point from period $t+1$ is compared to technology in an earlier period t. If technical progress has occurred, then a value of $\phi < 1$ is possible. Note that it could also possibly occur in equation (2.7) if technical regress has occurred, but this is less likely (Coelli et al., 2000, pp 227).

We need to solve the above four LPs for each district in each pair of adjacent years in the sample. Thus, in total we have solved 1,160 LPs for this study. We have used the Data Envelopment Analysis Program (DEAP) version 2.1, developed by Coelli (1996), to calculate all the LPs in this study.

2.3.2 Innovative Districts

In order to evaluate the regional disparities in the development of the agricultural sector of Bangladesh, we need to identify the districts which are shifting the frontier over time and playing the role as innovators. Decomposition of the productivity change allows us to identify the innovators who actually cause the best-practice frontier to shift (Horie and Yamaguchi, 2003).

Following Färe et al. (1994), to identify the innovative district, *k*, we can look at the component distance functions in the technical change index. If

technical change of a particular district k in the $t-th$ period >1

$d_o^t\left(y_{k,t+1}, x_{k,t+1}\right) > 1$, and

$$d_o^{k,t+1}\left(y_{k,t+1}, x_{k,t+1}\right) = 1 \tag{2.9}$$

then, that particular district can be regarded as innovator and having contributed to a shift in the frontier between period t and $t+1$.

Similarly, we can identify the efficient districts, if those particular districts fulfill all the three conditions mentioned in equation (2.10), while looking at the technical efficiency change index,

technical efficiency change of a particular district in the t -th period >1

$d_o^t\left(y_{t+1}, x_{t+1}\right) > 1$, and

$$d_o^{t+1}\left(y_{t+1}, x_{t+1}\right) = 1. \tag{2.10}$$

2.4 Data

The data set employed in this study is a panel of the former major twenty districts[10] for the period 1979 to 1999. Five outputs (rice, wheat, pulses, groundnuts, and til) and five inputs (land, labor, livestock, fertilizer, and irrigation) were considered for this study to construct the Malmquist TFP index. Note that only quantity data were used for this study due to unavailability of the complete and comparable set of prices of outputs and inputs for the districts under consideration.

Total rice represents six types of rice: Aus (local and HYV), Aman (local and HYV), and Boro (local and HYV). Wheat represents two types of wheat: local and HYV. Total pulses are consisted of five different pulses: masur, motor, mung, mashkhalai, and kheshari. Til represents both summer and winter production. The quantity data were collected from the sources mentioned in Section 1.4.2 and were measured in metric tons. Data for the intervening periods were calculated by interpolation assuming the inter-censal growth rate in the respective outputs.

Land covers the total cropped area (including area under multiple cropping) and it is measured in 1000 hectares.

Agricultural labor data at district level represents the total number of participants in the economically active population in agriculture regardless of differences in education, age, and sex. Since labor data at the district level are not directly available for all the years of our study period, we have followed a procedure in three steps to calculate the labor data series for all the districts.

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[10] Currently there are 64 districts, which were the parts of the former twenty districts. Till now, BBS publishes data on the former twenty districts rather than on the current 64 districts.

In the first step, we have listed the total population of all the districts for the study period which is given at different issues of statistical yearbook. In the second step, we have constructed the total labor force for the respective districts as a percentage of total population. In the final step, we have calculated the agricultural labor data as a ratio to the total labor force. The ratios of labor force and agricultural labor with respect to the total population and labor force respectively are given for different years. The intervening periods were calculated by interpolation assuming the intercensal growth rate.

The livestock variable used in this study is the aggregate of the various kinds of animals in livestock units irrespective of their age. It includes sheep, goats, cattle, and buffaloes. The conversions factors from livestock numbers to livestock units for cattle, buffaloes, sheep and goats are respectively 0.75, 1.31, 0.10, and 0.10 (Hossain, 1991, pp. 52). The data for the country as a whole and for the districts were obtained from Alauddin and Hossain (2001), different studies on agricultural and livestock censuses, and some other studies taken from time to time.

In this study, fertilizer variable is the sum of Urea, Triple Super Phosphate (TSP), and Muriate of Potash (MOP) which is measured in metric tons. The data were collected from various issues of the statistical yearbook and intervening period was calculated by interpolation assuming the inter-censal growth rate.

To construct the data for irrigation, this study follows the method used by Rahman (1999). The irrigation data represents the multiplication of irrigation index (measured as the irrigated area as a proportion of total cropped area) and area under modern varieties (measured as the proportion of total cultivable area under modern varieties of all rice and wheat crops). Thus, in this way the irrigation data would break the multi-collinearity between these two variables to a large extent.

Increased production of food grains has resulted more from an increase in the usage of capital rather than labor in Bangladesh (Alauddin and Tisdel, 1995). However, the time series data for capital use in agricultural production at district level are not available. Therefore, following Alauddin and Tisdell (1995), this study uses two proxies for capital, namely fertilizer and irrigation.

Weather plays an important role in the agricultural production. However, due to unavailability of data we have not included weather as a variable in the analytical framework.

It is worth mentioning that any analysis on Bangladesh agriculture encounters formidable problems of data quality (Jahan and Alauddin, 1996). The only comprehensive and major source of data is the Statistical Yearbook of Bangladesh, and recently published working paper by the CGPRT center. There are many studies, mainly by Pray (1980), Clay (1986), Boyce (1985), to identify the sources of errors and weakness of the data system. All those researchers found similar problems with the official agricultural statistics in Bangladesh.

Therefore, we have the only choice of using the published data while acknowledging their significant inadequacies. Since the price data are not available for the variables we use in this study, only the quantity data were considered to construct the Malmquist total factor productivity index. In this case, we are not able to calculate the allocative efficiency but we calculate the technical efficiency and productivity.

2.5 Result Analysis

The indexes of growth of each output and input are presented in graphical form in Figures 2.1 and 2.2, respectively. According to Figure 2.1, the growth rates of Pulses are comparatively higher than the other outputs. Since 1989, the growth rate of wheat has been remarkable and it exceeds the growth rate of rice. This is mainly due to the government policy of encouraging wheat production as a substitute for rice. The other outputs also increased, although the rates of growth are apparently different.

Figure 2.1: Indexes of Outputs

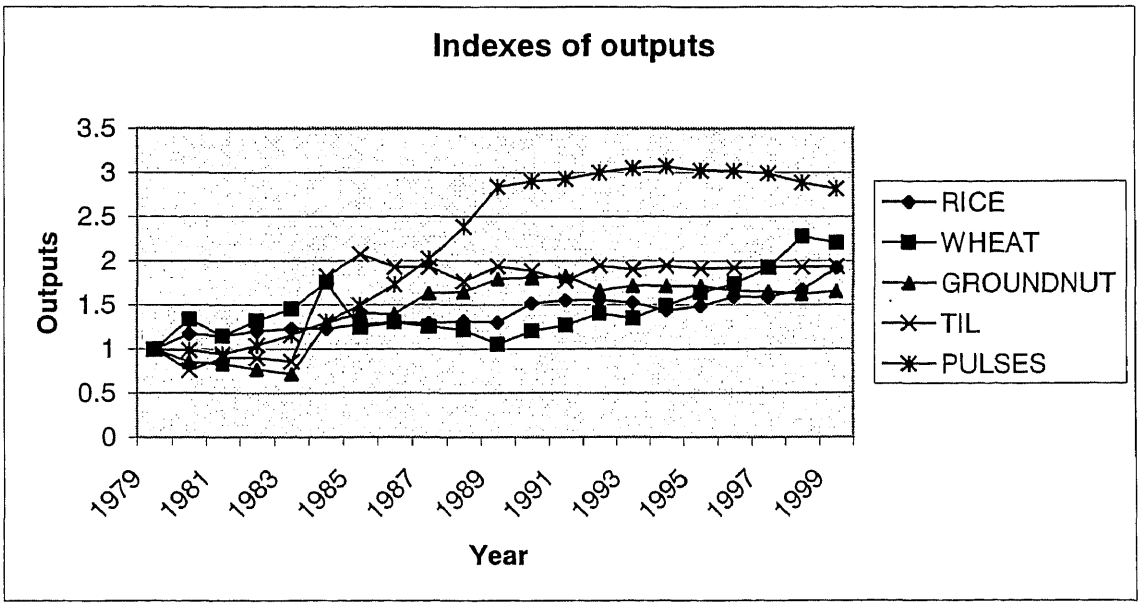
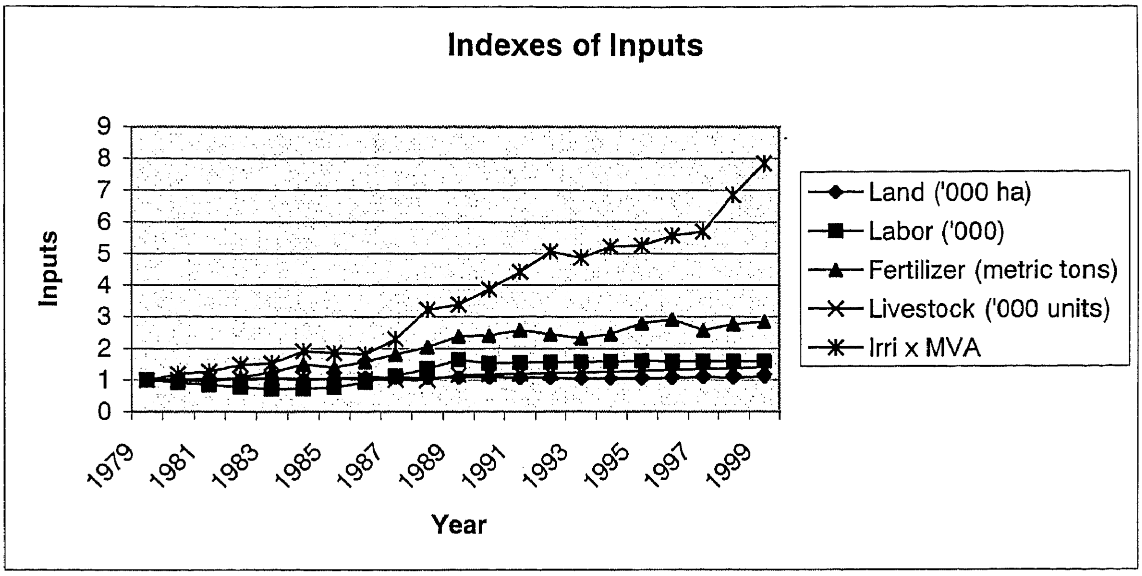


Figure 2.2 shows the cumulated indexes of the growth of five inputs. The growth rate of irrigation is very high than any other inputs. The below figure shows that land did

not grow much during the study period. Labor index shows that it became stagnant from 1990 onwards.

Figure 2.2: Indexes of Inputs



In this study, we have constructed the Malmquist productivity index relative to the constant return to scale using output orientation. Annual means and annual growth rates of the Malmquist productivity index and its components; technical efficiency change (TEC), and technological change (TC) are presented in Table 2.1.

Since the Malmquist productivity index is multiplicative, the averages are also multiplicative, i.e, the geometric mean. Improvements in agricultural productivity and its components occur when the values of the indices are greater than one. The value of the index at a point in time minus one indicates the percentage of growth (Färe et al., 1994).

Table 2.1 shows that agricultural productivity in Bangladesh increased at an annual growth rate of 0.90% over the 1979-99 period. During this period, the average annual growth rate in technical efficiency change and technological change was 0.20% and 0.70%, respectively. Therefore, the result shows that technological change is the main source of agricultural productivity growth in Bangladesh, which suggests that the new agricultural technology has helped the Bangladesh agriculture to grow during the study period.

Table 2.1: Annual Means and Annual Growth Rates of the Malmquist Index, and Its Components in Twenty Districts of Bangladesh, 1979-1999.

	Annual Means			Annual Growth Rates (%)		
	TEC	TC	TFP	TEC	TC	TFP
Dinajpur	1.000	1.001	1.002	0.00	0.10	0.20
Rangpur	1.000	0.975	0.975	0.00	-2.50	-2.50
Bogra	1.000	1.012	1.012	0.00	1.20	1.20
Rajshahi	1.002	1.010	1.012	0.20	1.00	1.20
Pabna	1.000	0.997	0.997	0.00	-0.30	-0.30
Kushtia	1.000	1.008	1.008	0.00	0.80	0.80
Jessore	1.010	1.020	1.030	1.00	2.00	3.00
Khulna	1.000	0.995	0.995	0.00	-0.50	-0.50
Barisal	1.043	1.002	1.044	4.30	0.20	4.40
Patuakhali	1.000	1.046	1.046	0.00	4.60	4.60
Mymensingh	1.000	1.010	1.010	0.00	1.00	1.00
Jamalpur	0.997	1.004	1.001	-0.30	0.40	0.10
Tangail	0.992	1.019	1.010	-0.80	1.90	1.00
Dhaka	0.997	1.016	1.013	-0.30	1.60	1.30
Faridpur	1.000	0.975	0.975	0.00	-2.50	-2.50
Sylhet	0.992	1.007	0.998	-0.80	0.70	-0.20
Comilla	1.008	1.008	1.016	0.80	0.80	1.60
Noakhali	1.000	0.991	0.991	0.00	-0.90	-0.90
Chittagong	1.000	0.996	0.996	0.00	-0.40	-0.40
Chit. H. T.	1.000	1.054	1.054	0.00	5.40	5.40
AVERAGE	1.002	1.007	1.009	0.20	0.70	0.90

Table 2.1 also shows the estimated Malmquist productivity index and its components for each district during the study period. The result shows that seven districts

out of twenty districts have negative productivity growth rates. They are: Rangpur (-2.50%), Pabna (-0.30%), Khulna (-0.50%), Faridpur (-2.50%), Sylhet (-0.20%), Noakahli (-0.90%), and Chittagong (-0.40%). The negative productivity growth rates in these districts (except Sylhet) are totally attributable to the negative growth in technological change since the growth rates of technical efficiency change are zeros.

Among the districts with positive growth rates, Barisal (4.40%), Patuakhali (4.60%) and Chittagong Hill Tracks (5.40%) showed remarkable growth rates compared to the other districts. The growth rates of Chittagong Hill Tracks and Patuakhali are fully attributable to the technological change and on the other hand technical efficiency change has a greater role (4.30%) in the productivity growth of Barisal.

Positive growth rates in technological change dominated the growth rates of technical efficiency change when comparing their relative importance in productivity growth in nine districts. They are: Dinajpur (0.20%), Bogra (1.20%), Rajshahi (1.20%), Kushtia (0.80%), Jessore (3.00%), Mymensingh (1.00%), Jamalpur (0.10%), Tangail (1.00%), and Dhaka (1.30%).

The growth rate of Comilla (1.60%) is contributed equally by the growth rate of technological change and technical efficiency change which are 0.80% each per annum.

Table 2.1 suggests that in twelve[11] out of twenty districts technical efficiency has no role in productivity growth. Therefore, the productivity growth (or decreases) in these twelve districts is fully attributed to the growth (or decreases) in technological change. Table 2.1 reveals that during the study period some districts enjoyed a very high productivity (e.g., 5.40% in Chittagong Hill Tracks), whereas some districts had as low as

[11] Twelve districts are: Dinajpur, Ranjpur, Bogra, Pabna, Kushtia, Khulna. Patuakhali, Mymensingh, Faridpur, Noakhali, Chittagong, and Chittagong Hill Tracks.

–2.50% (in Rangpur and Faridpur) productivity growth rate indicating the magnitude of disparities between the districts in Bangladesh.

The indexes of TEC, TC, and TFP are presented in Figure 2.3 which support the argument that technological change appears as the main source of productivity growth in Bangladesh agriculture.

Figure 2.3: Indexes of TEC, TC, and TFP

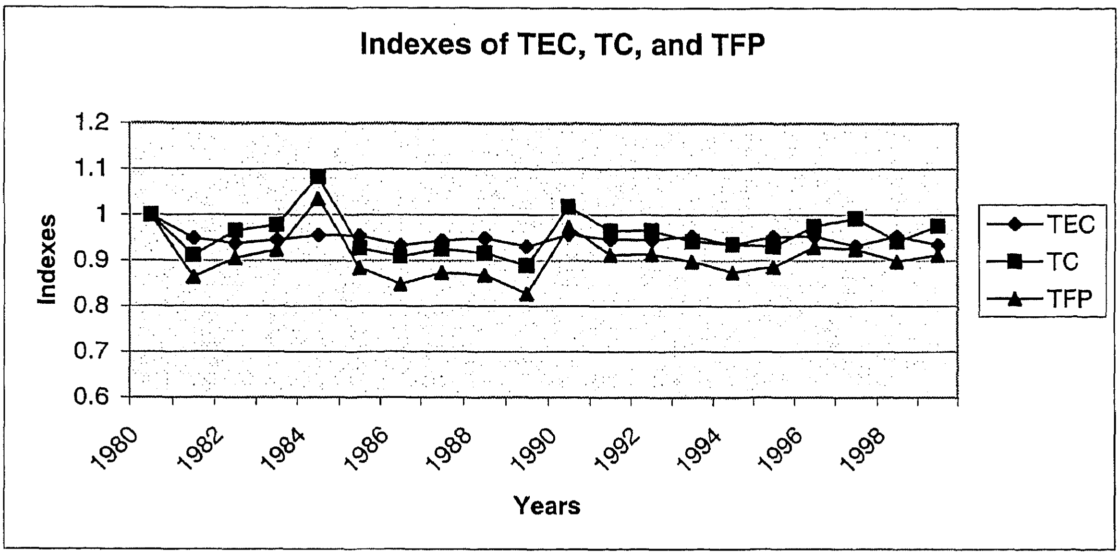


Table 2.1 does not show us to identify the districts which are shifting the frontier over time. In order to find out the innovative districts, we use equations (2.9) and (2.10) which were developed by Färe et al. (1994) and later used by many researchers. By looking at the component distance functions in the technical change index or technical efficiency change index, we can identify the innovative district.

The districts which satisfy all the conditions in equations (2.9) and (2.10) can be considered as the innovative districts. Table 2.2 shows the innovative districts in each year which actually shifted the frontier between *t-th* and *t+1-th* period. The asterisk (*) and number (#) marks in Table 2.2 indicate the innovative districts according to the conditions stated in equations (2.9) and (2.10), respectively.

As we see in Table 2.2, except Tangail all other districts satisfied the conditions stated in equation (2.9), and therefore, can be considered as the innovative districts and shifted the frontier at some point during the study period. Among all of them, Kushtia has shifted the frontier maximum 11 times during the twenty years study period. Each year a minimum of two districts (in 1981) to a maximum of thirteen districts (in 1990) have shifted the frontier in Bangladesh agriculture.

However, only eight districts have fulfilled the conditions stated in equation (2.10) which looks at the component distance functions in the technical efficiency change index. These districts are: Dinajpur (1980), Rajshahi (1984 and 1990), Jessore (1984 and 1985), Kushtia (1981 and 1987), Dhaka (1980), Sylhet (1987 and 1990), Comilla (1980), and Chittagong Hill Tracks (1984).

The results in Table 2.2 show that although except Tangail all other districts were innovative at different years during the study period according to technical change index, but only eight districts were innovative for six different years out of twenty years study period based on technical efficiency change index.

These findings point out that the districts in Bangladesh are using the available technology and helping to improve the productivity, but most of the districts are not technically efficient. As we also saw in Table 2.1, the productivity growth in Bangladesh was mainly contributed by the growth in technical change rather than improvements in technical efficiency.

Table 2.2: District Shifting the Frontier in Bangladesh Agriculture

Districts\Year (19..)	80	81	82	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97	98
Dinajpur	*#			*			*				*		*					*	*
Rangpur			*		*		*				*			*					
Bogra	*				*						*			*				*	
Rajshahi					#						*#		*						
Pabna			*		*		*		*		*	*	*		*			*	
Kushtia	*		*	*	*			*			*		*		*		*	*	*
Jessore					#	#	*	*	*		*	*	*		*	*		*	*
Khulna		*#	*		*			*#		*	*	*	*						
Barisal						*			*		*			*			*		
Patuakhali	*	*		*		*		*		*			*					*	*
Mymensingh	*																		
Jamalpur	*		*		*								*						
Tangail																			
Dhaka	#		*							*							*		
Faridpur			*				*	*			*		*			*	*	*	
Sylhet	*							*#			*#		*		*			*	
Comilla	*#		*								*		*						
Noakhali						*			*		*	*					*	*	
Chittagong	*		*	*		*						*				*		*	*
Chittagong Hill Tracks					#	*	*					*		*	*			*	

Tables 2.3 and 2.4 give us the list of the most and least five technical efficient and technologically developed districts, respectively for the four sub-periods (1979-1984, 1984-89, 1989-94, and 1994-99).

As we see in Table 2.3, the ranking of the districts moves from one sub-period to the other sub-period. Such as Dhaka was one of the five most technically efficient districts in the first two sub-periods and thereafter Dhaka was listed as one of the least efficient in the last two sub-periods. Similarly, Tangail was listed as one of the least efficient district in the first three sub-periods, however, it moved to the second most efficient district in the last sub-period. Table 2.3 shows that, there was no district which remain the most or least efficient throughout the study period. Therefore, it can be noted that there was no district which can claim as efficient constantly during the whole study period.

Table 2.3: The Most and Least Five Technically Efficient Districts

Rank	District	79~84	District	84~89	District	89~94	District	94~99
1	Barisal	1.182	Jessore	1.007	Sylhet	1.024	Mymensingh	1.022
2	Comilla	1.047	Dhaka	1.006	Jamalpur	1.023	Tangail	1.017
3	Jessore	1.032	13 remaining Districts	1.000	Rajshahi	1.007	14 remaining Districts	1.000
4	Rajshahi	1.006			Mymensingh	1.002		
5	Dhaka	1.006			14 remaining Districts	1.000		
16	12 remaining Districts	1.000	Mymensingh	0.998				
17			Rajshahi	0.994			Dhaka	0.996
18	Tangail	0.999	Sylhet	0.978			Jamalpur	0.990
19	Sylhet	0.998	Jamalpur	0.975	Tangail	0.989	Comilla	0.986
20	Mymensingh	0.979	Tangail	0.962	Dhaka	0.979	Sylhet	0.967

As we saw in Table 2.3, Table 2.4 also shows that the rankings of the districts move between the four sub-periods. Therefore, there was no district which listed consistently either as the most or least technologically developed district during the four sub-periods.

Tables 2.3 and 2.4 show that there were no common districts which could be recognized either the most efficient or the least efficient district irrespective of the methodologies we used to identify the ranking of the districts. On the other hand, we may say that there were no consistent characteristics of the districts in Bangladesh which might have kept them in the group of the most or least efficient lists.

Table 2.4: The Most and Least Five Technologically Developed Districts

Rank	District	79~84	District	84~89	District	89~94	District	94~99
1	Chi.HT	1.294	Patuakhali	1.071	Pabna	1.086	Dinajpur	1.080
2	Patuakhali	1.226	Noakhali	1.012	Barisal	1.075	Rajshahi	1.052
3	Bogra	1.082	Dhaka	0.998	Kushtia	1.059	Tangail	1.047
4	Kushtia	1.079	Khulna	0.997	Jessore	1.057	Jamalpur	1.043
5	Dinajpur	1.056	Barisal	0.986	Sylhet	1.046	Pabna	1.035
16	Khulna	0.985	Faridpur	0.935	Noakhali	1.005	Faridpur	1.001
17	Chittagong	0.985	Pabna	0.914	Khulna	0.980	Chittagong	0.994
18	Noakhali	0.966	Dinajpur	0.908	Dinajpur	0.971	Noakhali	0.981
19	Rangpur	0.964	Rangpur	0.907	Faridpur	0.969	Chi.HT	0.954
20	Pabna	0.963	Kushtia	0.895	Patuakhali	0.908	Barisal	0.899

We may say that the characteristics of the districts kept on changing from time to time which force them not to belong to the most or least efficient district lists throughout the study period. The change in characteristics might have caused by several external factors such as flood, rainfall, transportation, research and development, infrastructure, size of the land and farm, and etcetera.

From the above discussions, we have not found any district which performed consistently as the sole leader or determined the frontier in each year in Bangladesh agriculture. These results also indicate that disparities are found in the district level development.

Although our study failed to identify any single districts as the leader who can contribute significantly throughout the study period to shift the frontier or being innovative all the time, but on the basis of the productivity growth and discussions on the most developed or innovative districts, we can attempt to make a list of districts which may play the role model for the other backward districts. These are the districts which may be considered as the role model: Rajshahi, Jessore, Barisal, Comilla, and Chittagong Hill Tracks. The knowledge of these role model districts may be helpful to the neighbor or backward districts to overcome the disparities. The government has to take the initiative steps to spread the information on the achievements and know-how of the role model districts to the comparatively less developed districts.

2.6 Conclusion and Policy Implication

This paper has measured the Malmquist productivity index for the former twenty districts of Bangladesh and then decomposed the productivity index into technical efficiency index and technical change index. We have found that the average annual growth in productivity (0.90%) was mainly contributed by the growth in technical change (0.70%) rather than improvements in technical efficiency (0.20%).

These estimates are within a reasonable range compared with the other studies for Bangladesh agriculture. Rahman (2005) estimated a negative growth in technical efficiency (-1.00%), however, 0.90% of productivity growth rate was reported due to positive growth in technical change (1.92%).

We found that technical efficiency has no role in productivity growth in twelve out of the twenty districts. Therefore, the productivity growth (or decreases) in these twelve districts is fully supported by the growth (or decreases) in technological change.

The results in Table 2.2 shows that although except Tangail all other districts were innovative at different years during the study period according to technical change index, but technical efficiency change index shows that only eight districts were innovative for six different years out of twenty years study period.

These findings point out that the districts in Bangladesh are using the available technology and helping to improve the productivity, but most of the districts are not technically efficient.

Further, we have identified the most and least innovative districts on the basis of technical efficiency change index as well as technical change index for the four sub-periods. The results show us that the districts have shifted from the most to the least category between sub-periods during 1979-1999, and vice-versa. There were no districts which can be considered as the sole innovator or contributed to shift the frontier in Bangladesh agriculture.

However, there are some districts which have shown positive growth in all the indexes and also featured in the list of the most innovative districts by both methodologies. These districts can be chosen as the model districts and the government can plan a strategy to make available the knowledge and experience of these model districts to the lowly ranked districts to improve their productivity as well as to improve their technical efficiency and make them technologically developed districts.

Chapter 3

Convergence in Bangladesh Agriculture

3.1 Introductory Comments

The Malmquist productivity index[1] in Bangladesh agriculture shows that during the study period, 1979 to 1999, some districts enjoyed a very high productivity, (e.g., 5.40% in Chittagong Hill Tracks), whereas some districts had as low as –2.5% (in Rangpur and Faridpur) productivity growth rate which shows the magnitude of disparities between the districts in Bangladesh.

The overall growth in productivity at the national level indicates significant differences between those districts that have progressed rapidly and those that have lagged behind.

The differences in the rates of productivity growth in the various districts may be the result of regional inequalities. Therefore, it is important to understand the long-run movement in the district level productivity differences and take effective measures (such as higher investment in infrastructure, research and development, etc).

To promote the overall development of the economy and to reduce the district level disparities, the regional development in Bangladesh has been one of the main objectives of the government.

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[1] Please refer to Table 2.1.

In this chapter, therefore, we focus on the question of whether or not there has been a tendency towards convergence in agricultural productivity in the last two decades in Bangladesh over a representative cross-section of Bangladeshi districts.

We examine the question raised above using the different tests of convergence. As the cross-section tests for convergence hypothesis such as the Sigma (σ) and Beta (β) convergence are unlikely to be robust due to extremely small degrees of freedom. It is also appropriate to perform the test based on panel data framework.

Till date, there is only one study, by Rahman (2005), on convergence in Bangladesh agriculture. However, the data set they used for the study is little old and less number of districts was considered. This study includes more districts and the updated data to examine the extent to which the districts have converged in terms of agricultural productivity.

Our contribution to the existing literature is to explicitly test for convergence in agricultural productivity across Bangladeshi districts for a panel data set of twenty districts from 1979 to 1999 using a variety of test recently developed for estimating convergence in panel data models.

The plan of this chapter is as follows: In Section 3.2, we discuss the various approaches for convergence test. Section 3.3 provides discussion of the result and its relation to earlier studies on convergence, and we see that the Bangladesh experience has been similar to that in India and China. Section 3.4 concludes with the implications of the study.

3.2 Tests of Convergence

The neoclassical growth model without technology predicts convergence in output per worker for similar, closed economies based on the accumulation of capital. However, even in the neoclassical model, if the exogenous technology processes follow different long-run paths across countries, then there will be no tendency for output levels to converge.

If districts with low levels of productivity at the beginning of the period grow more rapidly than those with high initial productivity, convergence occurs, implying that the poorer districts are catching up (Thirtle et. al., 2003).

Empirical work on convergence has generally used either cross-section or time series techniques. Very recently, both cross-section and time series methods of testing convergence have been used extensively in the literature.

3.2.1 Cross Section Convergence Test

The cross-section analysis focuses on the tendency of countries or regions with relatively low initial levels of productivity, either defined as income per capita, labor productivity or total factor productivity, to grow relatively faster than high-productivity countries or regions. If the growth rates are regressed on the initial levels of productivity and the coefficient is negative, there is said to be Beta (β) convergence.

A test of β convergence is conducted by estimating regressions with the growth rate as the dependent variable and the initial level of productivity as the explanatory variable as follows:

$$g_{it} = \alpha + \beta y_{it} + \varepsilon_{it}, \tag{3.1}$$

where g_{it} is the productivity growth rate of region i between periods t and $t+k$, y_{it} is the initial productivity level in time t, α and β are the parameters and ε_{it} is an error term with zero mean and finite variance. Convergence is found to exist if the value of β is negative and significant. On the other hand, if β is positive there is divergence among countries or regions.

There is another concept, the Sigma (σ) convergence which predicts a narrowing dispersion of real per capita income (productivity) across regions or countries with the passage of time. Therefore, the σ convergence concerns with cross-sectional dispersion. The test of σ convergence holds if the cross-sectional standard deviation of the log of productivity decreases over time.

3.2.2 Panel Data Unit Root Test for Convergence

As discussed in literature, the empirical results based on σ and β convergence tests are not uniform indicating a reservation on the validity of the convergence hypothesis (Bernard and Durlauf, 1996; Evans and Karras, 1996; Quah, 1993;).

Recent studies of Levin and Lin (1992, 2002), Bernard and Jones (1996), Evans and Karras (1996), Im et al. (1997, 2003), and others have developed a variety of powerful tools for convergence tests based on panel data. This new technique for testing unit roots in panel data is a powerful tool compared to the univariate methodology.

In our study, we are interested in finding out whether the different districts in Bangladesh have managed to narrow their technology gap. To see this, we consider the approach proposed by Bernard and Durlauf (1995), and Bernard and Jones (1996) for testing convergence and is based on the time series properties of the productivity growth series.

Here, the issue of convergence is examined by testing whether the long-run forecasts of productivity differences tend to zero as the forecasting horizon tends to infinity. Essentially, this long-run convergence concerns the attainment of productivity equality.

3.2.2.1 Basic Model

Following Bernard and Jones (1996), we assume that the production process can be represented by a simple Cobb-Douglas production function with constant returns to scale. We can write the log of the output in agriculture in district i at time t, $\ln Y_{it}$, as:

$$\ln Y_{it} = \ln A_{it} + \alpha \ln K_{it} + (1-\alpha)\ln L_{it}, \tag{3.2}$$

where A_{it} is an exogenous technology process, K_{it} is the capital stock, and L_{it} is the number of workers in agriculture. We assume that A_{it} evolves according to:

$$\ln A_{it} = \gamma_i + \lambda \ln D_{it} + \ln A_{it-1} + \varepsilon_{it}, \tag{3.3}$$

with γ_i being the asymptotic rate of growth of agriculture in district i, λ parameterizing the speed of the catch-up denoted by D_{it}, and ε_{it} represents the region specific productivity shock. We allow D_{it}, the catch-up variable, to be a function of the productivity differential in agriculture in district i from that in district f, the most productive district,

$$\ln D_{it} = \ln \hat{A}_{it-1}, \tag{3.4}$$

where a hat indicates a ratio of a variable in district f, the most productive district, to the same variable in district i, i.e.,

$$\hat{A}_{it} = \frac{A_{ft}}{A_{it}}. \tag{3.5}$$

This formulation of productivity catch-up implies that productivity gaps between districts are a function of the lagged gap in productivity. The choice of the source of catch-up and the simple diffusion process is subject to criticism. Dowrick and Nguyen (1989) allow the catch-up to be determined by labor productivity differentials; however, it seems appropriate to suppose that technological catch-up may be occurring independent of capital deepening (Bernard and Jones, 1996).

Levin and Lin (1992) illustrated the relatively straightforward technique of testing for unit roots in panel data. Their basic findings are twofold: (1) that as both N and T go to infinity, the limiting distribution of the unit root estimator is centered and normal, and (2) that the panel setting permits relatively large power improvements.

More formally, consider the following general model,

$$y_{it} = \mu_i + \rho y_{it-1} + \varepsilon_{it}, \tag{3.6}$$

where the ε_{it} ~iid (0, σ_ε^2) and μ_i~iid ($\overline{\mu}, \sigma_\mu^2$). Here, it is also assumed ε_{it} has $2+\delta$ moments for some $\delta > 0$ and that $E\mu_i\varepsilon_{it} = 0$ for all i and t. Other standard regularity conditions are assumed to hold.

Let $\hat{\rho}$ and t_ρ be the OLS parameter estimate and t-statistic from a regression of y_{it} on y_{it-1} including country specific intercepts. The lemma[2] proved by Levin and Lin also holds when a common time trend is included in the regression.

3.2.2.2 Estimation Procedure

In chapter 2, we calculated the Malmquist productivity indexes for each district which was measured by using the Malmquist productivity index with respect to sequential frontiers. Therefore, for our model, let A_{it} represent agricultural multi factor productivity (MFP) in district i, $i=1,2,\ldots n$, at time t. The districts 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 others are compared. This best practice group is termed the frontier economy f, which may be a single district. MFP is assumed to develop according to:

$$\ln A_{it} = \gamma_i + \lambda \ln\left(\frac{A_{ft-1}}{A_{it-1}}\right) + \ln A_{it-1} + \varepsilon_{it}, \qquad (3.7)$$

---

[2] Lemma 1 (Levin and Lin): when $\overline{\mu} = 0$ and $\sigma_\mu^2 = 0$ (i.e, the unit root processes have no drift), if N and T go to infinity with $\sqrt{N}/T$ going to zero, $T\sqrt{N}\left(\hat{\rho}-\left(1-\frac{3}{T}\right)\right) \Rightarrow N(0,10.2)$, $\sqrt{1.25}t_\rho + \sqrt{1.875N} \Rightarrow N(0,1)$.

where γ_i is the asymptotic rate of growth of district *i*, the parameter λ characterizes the speed of catch-up, which is a function of the productivity differential between district *i* and district *f* and ε_{it} is the error term. Equation (3.7) implies that MFP in each district *i* may potentially grow either as a result of sector specific growth or as a result of technology transfer. If districts *i* is the most productive district, there is no technology transfer and equation (3.7) becomes,

$$\ln A_{ft} = \gamma_f + \ln A_{ft-1} + \varepsilon_{ft}, \tag{3.8}$$

combining equation (3.7) and (3.8), gives the expression for relative MFPs on which the tests are based,

$$\ln\left(\frac{A_{it}}{A_{ft}}\right) = \left(\gamma_i - \gamma_f\right) + \left(1-\lambda\right)\ln\left(\frac{A_{it-1}}{A_{ft-1}}\right) + \hat{\varepsilon}_{it}. \tag{3.9}$$

This equation can be estimated directly, and the augmented Dickey-Fuller (ADF) test with a drift is used to perform the test. If there is no catching up (λ=0), the difference between MFP in district *i* and in district *f* will contain a unit root (non-stationary). This means that productivity levels will permanently grow at different rates and no evidence of convergence is found.

In contrast, if λ>0, the difference between the technology levels in the two districts will be stationary, indicating evidence of convergence and implying that productivity differences should vanish in the long-run. The drift term $\left(\gamma_i - \gamma_f\right)$ will typically be small but non-zero if the districts' technologies are driven by a different process (that is, a null hypothesis of no convergence). Under the hypothesis of convergence, $\gamma_i = \gamma_f$ is plausible. Therefore, only if λ>0 and $\gamma_i = \gamma_f$ will districts converge.

3.3 Estimation Results

3.3.1 Beta Convergence Test

To test β convergence, we regressed the growth rate of productivity with the initial level of productivity and a constant as mentioned in equation (3.1). The results of this test are reported in Table 3.1. The estimated parameter, the coefficient of the initial productivity level, is negative and significant at 1% confidence level. Therefore, the results provide strong evidence that agricultural productivity in Bangladesh at district level has converged. In other words, districts with initial poor level of productivity grew faster and are catching up with the high productivity districts.

Table 3.1: Testing for Beta (β) Convergence

Period	Variable	Coefficient	SE	t-statistics	R-squared
1979-1999	α	1.0408	0.0034	308.225*	0.91
	β	-0.0392	0.0028	-13.925*	

Note: * denote significant at 1% level.

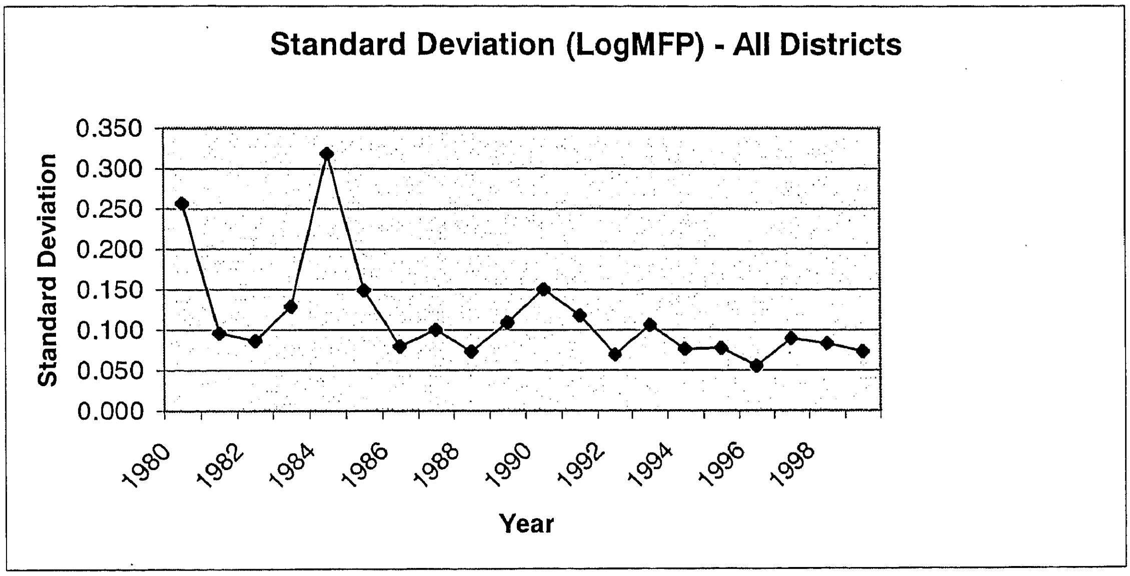
3.3.2 Sigma Convergence Test

As mentioned by Sala-i-Martin (1996) that β convergence is a necessary but not a sufficient condition for σ convergence. Further, β convergence does not guarantee a reduction in the distribution of dispersion among multi factor productivity growth rates.

The results from σ convergence tests, the cross sectional standard deviations for the log of MFP over time, are shown in Figure 3.1.

It seems apparent that overall, there has been a decrease in the cross-districts dispersion of MFP in agriculture over the entire time period. The movement has been very uneven, with sharp increases followed by significant declines in productivity dispersion.

Figure 3.1: Sigma (σ) convergence: Standard Deviation of the Logarithm of MFP



There are two distinct trends that can be observed in the Figure 3.1. Firstly, from 1980 till 1990 there has been very uneven movement with sharp fluctuations in 1984. Secondly, from 1990 onwards there is a decrease in MFP dispersion except in 1993 and 1997. The dispersion level decreases from 0.26 at the beginning of the period to 0.08 in 1999.

Our results on σ convergence test shows that agricultural productivity at district level in Bangladesh is converging, which further corroborate the result obtained from β convergence test.

3.3.3 Panel Based Convergence Test

One issue to be considered when testing for convergence using the time series approach is how to choose the benchmark district. Bernard and Jones (1996) argued that the choice should not matter, but in small samples, it will be more appropriate to use the most productive district at the beginning of the sample. In our study, Barisal district is used as the benchmark since they have the highest productivity level at the beginning of the study period[3].

Further, to correct for possible serial correlation, a lag is included in equation (3.9). The most appropriate lag length is then chosen according to the Schwarz information criterion. However, the results from using different lag length are very similar. Our results from the panel unit root test are reported in Table 3.2.

The value of estimated coefficient $(1-\lambda)$, i.e., coefficient of the lagged agricultural MFP, is –0.9991, which indicates that the value of λ is 1.9991. The t-statistics (-18.6129) rejects the null hypothesis of a unit root and, therefore, dispersion of productivity is stationary providing strong evidence that the districts do exhibit long-run convergence. Thus, the unit root test supports the conventional test and primarily we can conclude that there is evidence of convergence.

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[3] Please refer to Appendix II (Table A2).

Table 3.2: Panel Unit Root Test for Convergence

Variable	Coefficient	SE	t-statistics
$(\gamma_i - \gamma_f)$	0.0070	0.0099	0.7096
$(1-\lambda)$	-0.9991	0.0537	-18.6129*

Note: * denote significant at 1% level.

Further, the drift term $(\gamma_i - \gamma_f)$ is 0.0070 which is very small and that can be treated as approximately zero. The null hypothesis that the drift term is zero cannot be rejected at 1% confidence level, thereby confirming that $\gamma_i = \gamma_f$. Therefore, both the condition of $\lambda > 0$ and $\gamma_i = \gamma_f$ hold in our case and jointly confirm that there is strong evidence of long-run convergence among districts. We can finally conclude that there is a tendency towards convergence among districts in Bangladesh agriculture. To support our argument, we draw Figure A1 (in Appendix III) which shows the similar pattern of productivity growth rates among selected districts[4] over time. Figure A1 also indicates the existence of convergence in the long-run in Bangladesh agriculture.

Our findings on productivity convergence in Bangladesh should not be treated as exceptional. There is mixed evidence of convergence in agricultural productivity and its components in both Asia and Africa.

For example, Mukherjee and Kuroda (2003) noted that there is evidence of conditional long-run convergence in agricultural productivity among states of India towards an all-India average TFP estimate. Wu (2000) found that overall TFP growth in

[4] We choose six districts, three each above and less than the national average, to make the graph less crowded. The other remaining fourteen districts also shows the same pattern.

China has shown signs of convergence since the 1990s with technical efficiency across regions having converged as early as the 1980s.

On the other hand, Teruel and Kuroda (2005) indicates that productivity gaps are not narrowing or less productive regions are not catching-up to most productive region or even to average region in the Philippine agriculture. Thirtel et al. (2003) found no evidence of convergence among 18 districts of Botswana. Using a panel of 18 Asian countries, Suhariyanto and Thirtle (2001) found empirical evidence of productivity divergence.

Very recently, Rahman (2005) attempted to examine convergence in Bangladesh agriculture for 16 districts from 1964 to 1992. The data set used in Rahman (2005) were taken from Deb (1995), and the study period starts when the green revolution technology was introduced in Bangladesh agriculture. Our results corroborate with the findings of Rahman (2005), who concluded that divergence among regions disappeared and agricultural productivity reached convergence in the long-run.

3.4 Concluding Comments

This chapter analyses convergence in multi factor productivity (MFP) growth in Bangladesh agriculture across twenty districts from 1979 to 1999. We used both cross-section and time-series tests to determine if there is narrowing down of productivity dispersion or catch up in regional productivity to a certain level.

Our results show that the estimated parameter β, the coefficient of the initial productivity level, is negative and significant indicating convergence in growth of regional productivity. The σ convergence test, which was calculated by the cross-sectional standard deviations for the log of MFP, confirmed that the productivity differences among districts are narrowing over time. The panel unit root test further showed that divergence among districts disappear and agricultural productivity reach convergence in the long-run.

This is a positive finding, from a policy perspective, as it implies possible reduction in regional inequality in agricultural productivity in the long-run. However, this result raises a question: whether convergence took place due to the slowing down of the most productive districts to match growth performance of the less productive districts instead of the latter group catching-up with the frontier. Further research should address these issues which will remain a challenging task for the policy makers in the future.

Chapter 4

Causality between Capital Investment and Productivity in Japanese Agriculture, 1957-97*

4.1 Initial Comments

Japanese agriculture has experienced a rapid growth in productivity from the mid 1950s to the early 1970s. The growth rate was 1.52% for the period 1957-71. Concurrently, capital investment[1] in Japanese agriculture also grew at a rapid rate during the same period. The growth rate of capital investment was 5.56% between 1957-71. This indicates that 'learning-by-doing' and 'technological spillover' process may have been working during this period in Japanese agriculture.

However, over the past two decades the productivity grew at a relatively lower rate compared to the earlier period.[2] Between 1972-84 and 1985-97, the annual average growth rate of productivity was 0.18% and 0.12% respectively. We have also noticed that the growth rate of capital investment per year has continuously decreased during the same period.[3] The growth rate was 2.79% during the 1972-84 period and it became negative (-0.38%) in 1985-97 period. The reason for the decreasing trends in productivity growth rates and capital investment during this period might be because of technological

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* This chapter is based on Rahmatullah and Kuroda (2005).

[1] Capital consists of machinery, other inputs, and land. Other inputs include buildings and structures, plants, and animals.

[2] Refer to Table A3 (in Appendix II) for TFP growth rate for the period 1957-97 among the different size classes.

[3] Refer to Tables 4.2 and 4.3 for capital growth rate for the 1957-97 period.

regression, decrease in demand for agricultural commodities, and increase in costs of machinery inputs and farm buildings and structures.

Thus, it is interesting to note that both capital investment and productivity in Japanese agriculture had fairly high growth rates until the 1970s and then afterwards it started decreasing till the end of the period under study. Why have both capital investment and productivity growth rates been increasing and decreasing simultaneously? What has been the connection between capital investment and productivity in Japanese agriculture during the periods of rapid and slow growth? Do they cause each other, and if so, then in which direction?

To analyze economic aspects of the growth, Arrow (1962), Sheshinski (1967), and Romer (1986) develop learning-by-doing models which postulate that a level of technical knowledge is approximated by an accumulated level of the capital, and that the knowledge spills over an entire economy. Thus capital investment generates technological progress through the learning-by-doing and the spillover idea.

Oniki (2001) used the Granger causality tests and found that the productivity growth associated with capital investment on Japanese rice production and further suggested a positive public interventions to provide incentives to innovative producers. These findings lead us to investigate the long-run relationship between the productivity and capital investment to confirm the learning-by-doing process in Japanese agriculture for aggregated output.

Therefore, it is of great interest to test for the causality between productivity and capital investment. Accordingly, the objective of this study is to investigate the causal relationship between total factor productivity (TFP) and capital investment in Japanese agriculture for the 1957-97 period, and to find out the direction of causality.

We have found that a substantial number of studies on postwar Japanese agricultural productivity have been carried out by Yamada (1982, 1984), Yamada and Hayami (1979), Yamada and Ruttan (1980), Kuroda (1988, 1989, 1997), Van Der Meer and Yamada (1990), and Ito (1992), to name only a few. Their works were focused on measuring and decomposition of TFP, linking the growth of TFP to the theory of production, biased technological change, and factor demand in postwar Japanese agriculture, etc. However, we have found that there have been few attempts to establish a relationship between TFP and the variables that explain TFP growth in Japanese agriculture.

Like many papers of the past this paper also measures TFP; however, it differs in a few aspects. It has used a larger sample size after the postwar and used pooled data. This paper used the multilateral index proposed by Caves, Christensen and Diewert (1982) (hereafter called the CCD method)[4] to measure the total output, total input and TFP indexes. This paper measures the aggregated output index (which consists of five outputs) and the aggregated input index (which consists of five inputs) for measuring the TFP index.

There have been several studies on the causality concept in international agricultural economics, which include test of the export-led growth hypothesis, the induced innovation hypothesis, price dynamics, market integration, and linkages between

[4] The CCD method is most relevant for the estimation of the Törnqvist index for a pooled cross-section of a time-series data set. This procedure was used in Kuroda (1988, 1989, 1997) in estimating TFP index.

the macro economy and agriculture. However, there are very few studies on this issue on Japanese agriculture.

Oniki (2001) used the time series-based econometric analysis on Japanese rice production to provide evidence supporting the technological change process of learning-by-doing and technological spillover. The learning-by-doing effect was confirmed by cointegration between the capital and the total factor productivity and the technological spillover effect was confirmed by the Granger (1988) causality tests for the TFP of large-scale producers and that of small-scale producers.

It has been found that most of the earlier studies on causality used time series data. Recently, there have been a few studies on foreign direct investment and trade, effect of public infrastructure on productivity, and between agricultural R&D and productivity which have used panel data to test for causality.

Schimmelpfennig (1992) extends Granger's test to handle panel data in a linear model. Schimmelpfennig and Thirtle (1994) presented a restricted versus unrestricted model to test Granger causality between TFP and R&D expenditures for the ten European Countries (EC) and the USA. This study follows the Schimmelpfnnig and Thirtle's (1994) model to test causality between TFP and capital investment in Japanese agriculture.

This paper differs from past research in several ways. It is the first paper to use causality testing between TFP and the variables that explain TFP, i.e., capital investment, in Japanese agriculture for aggregated output. In the way of causality testing, we will derive a capital and TFP index.

While deriving the capital index, we will use two models to check the behavior of land (does it play a fixed input role or not?). This paper attempts to test the existence of a long-run relationship between TFP and capital and the direction of the relationship between them.

The rest of this paper is arranged as follows. Section 4.2 presents the analytical framework. Section 4.3 describes the sources and definitions of the variables and the data used in this study. Section 4.4 contains the empirical results and analysis. Finally, conclusions are drawn in Section 4.5.

4.2 Analytical Framework

The analysis presented in this study is basically divided into two major parts. The first part will deal with the measurement of productivity in Japanese agriculture. While measuring productivity, it will investigate the movements in total output, total input and total factor productivity (TFP) for average farms of four size classes, 0.5-1.0 (I), 1.0-1.5 (II), 1.5-2.0 (III), and 2.0 hectares or larger (IV) for the 1957-97 period. The second part will investigate the direction of causality between the capital investment and productivity.

4.2.1 Productivity Measurement

In order to draw an overall perspective on the Japanese agriculture sector, total output, total input, and TFP indexes are computed for the total average farm of the four size classes by using the shares of the number of farm households as weights.

For the measurement of the indexes of total output, total input, and TFP, the conventional Divisia aggregation procedure is employed.[5] The Divisia indexes for aggregate output (Q) and input (F) are defined in terms of proportional rates of growth ($\dot{Q}$ and $\dot{F}$) as

$$\dot{Q} = \sum_j \frac{q_j Q_j}{R} \bullet \dot{Q}_j \tag{4.1}$$

and

$$\dot{F} = \sum_i \frac{P_i X_i}{C} \bullet \dot{X}_i \tag{4.2}$$

Where q_j and Q_j are respectively the price and quantity of output j; P_i and X_i are respectively the price and quantity of input i; $R = \sum_j q_j Q_j$, the total revenue; $C = \sum_i P_i X_i$, the total cost; and $\dot{Q}_j$ and $\dot{X}_i$ are the proportional rates of growth of output j and input i, respectively.

Since TFP = Q/F, the proportional rate of growth of total factor productivity ($\dot{TFP}$) is defined by

$$\dot{TFP} = \dot{Q} - \dot{F} \tag{4.3}$$

The formulas (4.1) to (4.3) are, however, in terms of instantaneous changes. The data to be used in this study are available at yearly intervals. The Törnqvist (1936) discrete approximation procedure is then introduced to the formulas (4.1) and (4.2).

$$\Delta \ln Q = \ln\left(\frac{Q_t}{Q_{t-1}}\right) = \frac{1}{2}\sum_j \left(R_{jt} + R_{jt-1}\right) \ln\left(\frac{Q_{jt}}{Q_{jt-1}}\right) \tag{4.4}$$

[5] The formulation draws heavily on Denny et al (1981, pp. 187-188) and Kuroda (1989, pp. 148).

$$\Delta \ln F = \ln\left(\frac{F_t}{F_{t-1}}\right) = \frac{1}{2}\sum_i \left(S_{it} + S_{it-1}\right)\ln\left(\frac{X_{it}}{X_{it-1}}\right) \quad (4.5)$$

Where $R_j = \frac{q_j Q_j}{R}$, the revenue share of output j; $S_i = \frac{P_i X_i}{C}$, the cost share of input i; and t denotes time period. The corresponding discrete approximation to formula (4.3) is given by,

$$\Delta TFP = \Delta \ln Q - \Delta \ln F \quad (4.6)$$

Using (4.4), (4.5), and (4.6), the indexes of total output, total input, and TFP will be measured for the average farm in each size class together with the total average for the 1957-97 period. This study uses the CCD multilateral index procedure to measure the indexes of total output, total input, and TFP.

4.2.2 Causality Testing

To test the null hypothesis that 'x does not cause y', we regress y against lagged values of y and lagged values of x (unrestricted model), and then regress y only against lagged values of y (restricted model). The Lagrange multiplier (LM) test can then be used to determine whether the lagged values of x contribute significantly to the explanatory power of the first regression. If they do, we can reject the null hypothesis and conclude that the data are consistent with x causing y. The null hypothesis that 'y does not cause x' is then tested in the same manner.

Unrestricted model: $$y_{it} = \mu_i + \sum_{j=1}^{m} y_{it-j}\alpha_j + \sum_{j=1}^{m} x_{it-j}\beta_j + u_{it} \quad (4.7)$$

Restricted model: $$y_{it} = \mu_i + \sum_{j=1}^{m} y_{it-j}\alpha_j + u_{it} \quad (4.8)$$

For this study, in the above equations (4.7) & (4.8), y and x represent TFP and capital respectively, j = 1,....,m, is the number of lags chosen, i represents the size classes, so the μ_i are size class specific fixed effects, t is the number of years of observations and each u_{it} satisfies the classical zero conditional mean, no serial correlation and homoscedasticity assumptions. The assumption made here is that the coefficients α_j and β_j are the same across the size classes in the sample.

It is possible to test different numbers of lags of TFP and capital together in the panel data model, but there is no final prediction error criterion, so we use the common assumption that the lags of TFP and capital should be the same.

The estimation problem for this model is that fixed effects panel data specifications with lagged dependent variables yield inconsistent results. However, once the fixed effects are removed by the standard technique of first differencing, the pooled data model become consistent. Then the model is,[6]

$$\Delta y_t = \sum_{j=1}^{m} \Delta y_{t-j}\alpha_j + \sum_{j=1}^{m} \Delta x_{t-j}\beta_j + u_t \quad (4.9)$$

Since we will be testing causality between TFP and capital, the equation can thus be rewritten as:

$$\Delta TFP_t = \sum_{j=1}^{m} \Delta TFP_{t-j}\alpha_j + \sum_{j=1}^{m} \Delta K_{t-j}\beta_j + u_t \quad (4.10)$$

$$\Delta K_t = \sum_{j=1}^{m} \Delta K_{t-j}\delta_j + \sum_{j=1}^{m} \Delta TFP_{t-j}\theta_j + v_t \quad (4.11)$$

[6] The formulation is given in D. Schimmelpfennig and C. Thirtle (1994), "Cointegration and Causality: Exploring the relationship between agricultural R&D and Productivity", pp. 228.

For there to be unidirectional causality from capital to TFP, the estimated coefficient on lagged capital (K) in equation (4.10) should be significantly different from zero as a group $\left(\sum \beta_j \neq 0\right)$, and the set of estimated coefficients on lagged TFP in the equation (4.11) should not be significantly different from zero $(\sum \theta_j = 0)$.

Bidirectional causality is suggested when both $\sum \beta_j \neq 0$ in (4.10) and $\sum \theta_j \neq 0$ in (4.11), and independence when both sets of coefficients are not significantly different from zero.

To test the joint significance of the β_j's, the LM test statistic for the restricted versus the unrestricted model is computed[7]. This statistic has a χ^2 limiting distribution, with degrees of freedom equal to the number of β_j's, which is number of lags (m)[8].

For the estimation of equation (4.10) & (4.11), we need to have two series of indexes: TFP and capital. The index of TFP will be calculated from equation (4.6). There will be two models while calculating capital. In model one, capital (K1) consists of machinery, other inputs, and land. In model two, capital (K2) will consist all the above variables except land. The determination of capital stock will follow the same indexation procedure as aggregate input.

$$\Delta \ln K = \ln\left(\frac{K_t}{K_{t-1}}\right) = \frac{1}{2}\sum_i \left(M_{it} + M_{it-1}\right)\ln\left(\frac{D_{it}}{D_{it-1}}\right) \tag{4.12}$$

where K represents capital; $M_i = \frac{G_i \bullet D_i}{T}$, the cost share of capital i; G_i and D_i are respectively the price and quantity of capital i; $T = \sum_i G_i D_i$, the total cost; and t denotes

[7] Refer to Maddala (1992) and Pindyck and Rubinfeld (1998).

[8] Dickey and Fuller (1981) unit root was tested for each variable and we have found that all the variables are integrated of order one and therefore, the null hypothesis of a unit root is accepted.

time period. The CCD multilateral index procedure will be used to construct the index of capital.

4.3 Data

The data required for the estimation of the model are the total cost, total revenue, the prices and quantity of output, the prices and quantity of input, revenue share of output, and cost shares of the five factor inputs: labor, machinery, intermediate inputs, land, and other inputs.

Eleven different items of outputs were classified into five categories: rice, vegetables, fruits, livestock, and others, to construct total output. Other outputs include wheat and barley, grains and beans, various potatoes, industrial crops such as tea, rice stalks and processing of rice stalks, and other crops. The base of all indexes was set at 1985 values.

As we mentioned earlier, pooled data is used for this study. To measure the quantity and price indexes of total output and total input, a multilateral index proposed by Caves, Christensen, and Diewert (1982) (CCD) is employed.

Total revenue, the value of outputs and price indexes (1985=100) of the various outputs are given in the data series. The revenue share (R_i) was obtained by dividing the revenue on each category of outputs (P_iQ_i) by the total revenue (R).

The quantity and price indexes of machinery (X_M and P_M), intermediate inputs (X_I and P_I), and other inputs (X_O and P_O) were also constructed by the CCD method. In these computations, the cost of machinery (P_MX_M) was defined as the sum of the costs for machinery, energy, and rentals; the cost of intermediate inputs (P_IX_I) as the sum of the expenditure on fertilizer, seed, agrochemicals, materials, clothes, and others; and the cost of other inputs (P_OX_O) as the sum of the expenditures on animals, plants, and farm buildings and structures. The necessary data were taken from the FHE. In addition, the price data necessary for computing the CCD indexes were obtained from the PWRV.

The quantity of labor (X_L) was defined as the total number of male-equivalent labor hours of exchange, family, permanent and temporary hired workers. The number of male-equivalent labor hours by female workers was estimated by multiplying the number of female labor hours by the ratio of female daily wage rate to male wage rate, which was obtained annually from the PWRV. The price of labor (P_L) was obtained by dividing the wage bill for temporary hired labor by the number of male equivalent labor hours of temporary hired labor. The labor cost (P_LX_L) was defined as the sum of the labor cost for exchange and family workers, and the wage bill for hired labor.

The quantity of land (X_T) was defined as the total planted area. The price of land (P_T) was obtained by dividing the cost for rented land by the rented land area (1000 Yen per 10 areas). Land cost is computed as follows: CXT=(PT.X1)+X3+X4:

Where PT = X3/X2;

X1: Own arable land area [X1= Total arable land area – Rented land area].

X2: Rented cultivated land area.

X3: Rent payment.

X4: Expenditure on land improvements and water use.

Finally, the total cost (C) was defined as the sum of the expenditures on these five categories of factor inputs, i.e. $C = \sum_{i=1}^{5} P_i X_i$ (where, i = Land, Machinery, Intermediate inputs, Labor, and Other inputs).

The cost share (S_i) was obtained by dividing the expenditure on each category of factor inputs ($P_i X_i$) by the total cost (C).

4.4 Empirical Results and Analysis

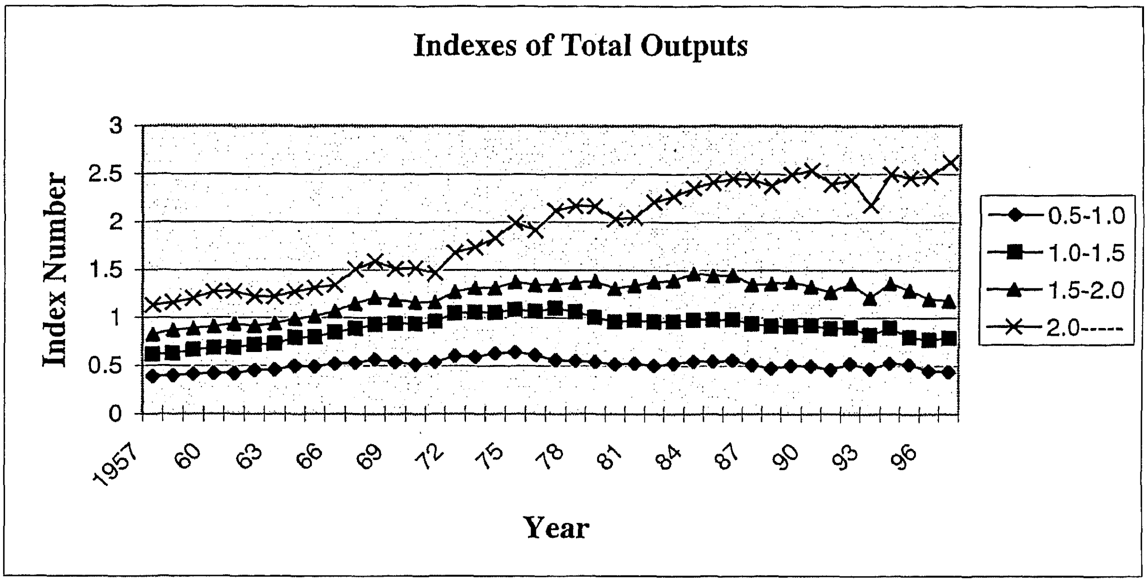
This section discusses the results found from productivity measurement and causality testing. The empirical results and interpretations are presented in the following sub-sections.

4.4.1 Results of the Productivity Measurement

The estimates of the indexes of total output, total input, and TFP are presented in graphic form in Figure 4.1, 4.2, and 4.3, respectively. According to Figure 4.1, total output increased in all size classes for the 1957-97 periods, although the rates of growth are apparently different among the size classes.

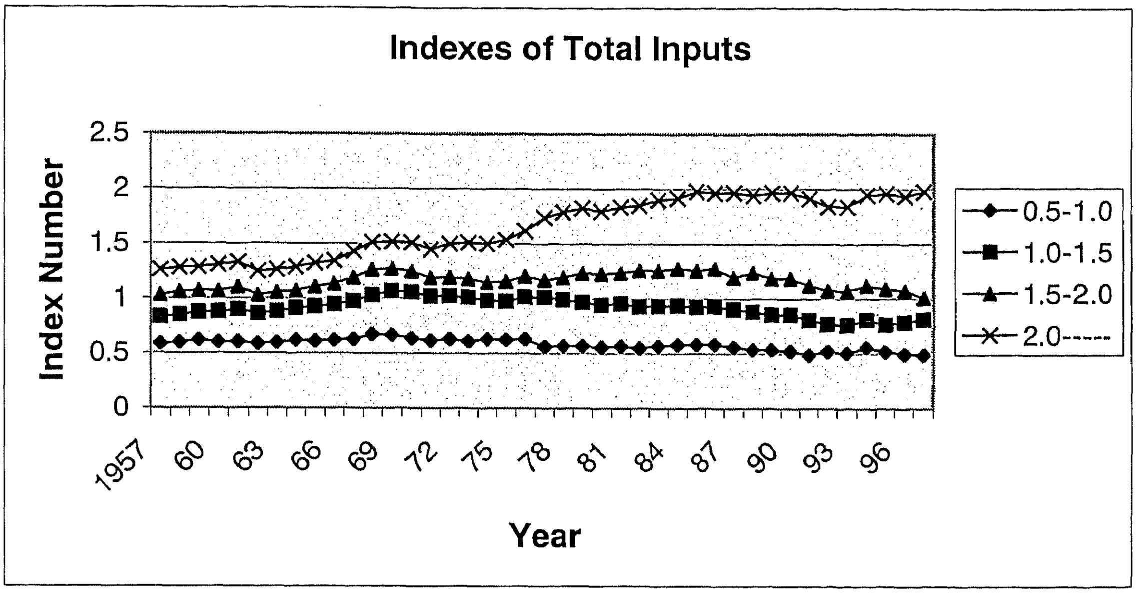
In the smallest size class (I), total output of average farms declined in the late 1970s, and then it became almost stagnant. Total output of average farms in size class II also started declining in the late 1970s, and continued to decline till the end of this study period. However, total output of size class III continued to increase till 1985, and then started declining. Total output of average farms in the largest scale farm (IV) increased in general throughout the study period, and growth of total output of this size class was remarkable compared with those of the other classes.

Figure 4.1: Indexes of Total Outputs (1957-97)



In Figure 4.2, we see that the patterns of growth of total input seem to have been different among different size classes. Total input of the largest size class (IV) slightly declined in the early 1960s, and immediately after that it started growing and grew continuously throughout the study period. The growth of total input of the other three size classes (I, II, and III) did not increase compared to the growth of the size class IV.

Figure 4.2: Indexes of Total Inputs (1957-97)



Finally, the movement of TFP is given in Figure 4.3. The graph shows that the patterns of the growth of TFP are almost similar among all size classes. Until 1970s, the growth of TFP in smaller size classes grew at a faster rate compared to the larger size classes. From 1980s, the growth of TFP in all size classes shows same pattern.

Figure 4.3: Indexes of Total Factor Productivity

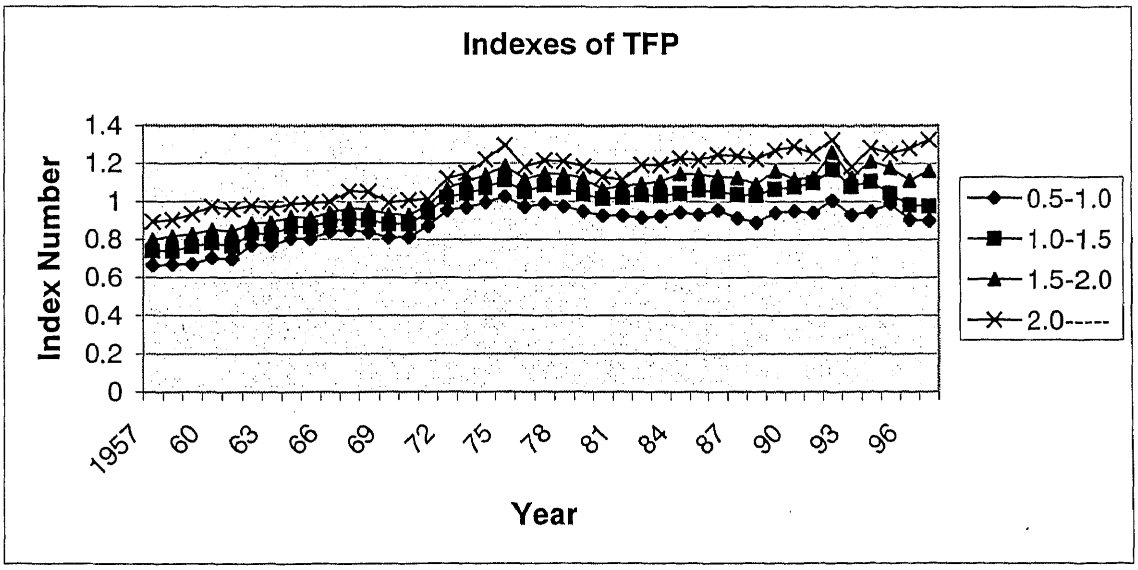


Table 4.1 shows the growth rate of total output, total input, and TFP for all size classes. The annual growth rates of TFP in size class III (0.92%) was greater than those in other size classes.[9]

Table 4.1: Growth Rates of Total Output, Total Input, and TFP (1957-97)

Size Class	Total Output ($\dot{Q}$) (1)	Total Input ($\dot{F}$) (2)	$\dot{TFP}$ (3) = (1) − (2)
0.5-1.0 (I)	0.2315	- 0.5298	0.7613
1.0-1.5 (II)	0.5357	- 0.3233	0.8590
1.5-2.0 (III)	1.0324	0.1171	0.9153
2.0---- (IV)	2.2318	1.3308	0.9010
Average	1.0079	0.1486	0.8593

Note: (Unit:%)

4.4.2 Results of Causality Testing

Capital index of all the size classes are given in graphic form in Figures A2 and A3 (see Appendix III). The growth rates of capital among the different size classes are calculated and given in Tables 4.2 and 4.3.

Table 4.2: Growth rates of Capital (K1) Among Size Classes. (Unit: %)

Year\Size class	0.5-1.0 hectare (I)	1.0-1.5 hectare (II)	1.5-2.0 hectare (III)	2.0---or more hectare (IV)	Average
1957-1971	5.6322	6.1850	5.3655	5.0490	5.5565
1972-1984	1.8227	1.8578	2.9625	4.5006	2.7859
1985-1997	-0.4959	-0.7898	-0.9431	0.7081	-0.3801
1957-1997	1.6373	1.7110	1.9301	3.0825	2.0902

Note: Capital (K1) consists of machinery, land, and other inputs.

[9] These estimates are within a reasonable range, compared with the other studies for Japanese agriculture. Due to the substantial changes in average farm size of sample farmers in 1992 and 1995, there was a sharp decrease in the TFP index for all the size classes in 1993 and in 1996, except for the size class IV, the three other size classes (I, II, and III) had further decreases in TFP measurement.

We have divided the study period (1957-97) into three sub-periods in order to understand the decreasing trend in the growth rate of capital among the different size classes. From Table 4 we see that the growth rate of capital is decreasing in all the size classes. During the first sub-period (1957-71), the growth rate of capital was very high among all the size classes. This is mainly because of farm mechanization and increased utilization of fertilizer, and agrochemicals in Japanese agriculture. Thereafter, the growth rate started decreasing and became negative in the third sub-period (1985-97) in all the size classes except size class IV. This is because of smaller-scale farms decreased their usage of fertilizer, agrochemicals, and feed. Table 4.3 also shows the same result where capital consists of machinery and other inputs.

Table 4.3: Growth rates of Capital (K2) Among Size Classes. (Unit: %)

Year\Size class	0.5-1.0 hectare (I)	1.0-1.5 hectare (II)	1.5-2.0 hectare (III)	2.0---or more hectare (IV)	Average
1957-1971	8.5891	9.1036	7.9764	7.5146	8.2959
1972-1984	2.6044	2.6582	4.0645	5.7830	3.7775
1985-1997	-0.4882	-0.7975	-0.9027	0.6697	-0.3796
1957-1997	2.6476	2.7188	2.9536	4.1659	3.1214

Note: Capital (K1) consists of machinery, and other inputs.

We have derived TFP index from productivity measurement section (equation 4.6). We have used lags of TFP index and lags of capital index to test causality between them.

The test results of the Granger causality between TFP and capital, as well as capital and TFP are presented in Table 4.4 and Table 4.5.

The first column of Table 4.4 shows the number of lags chosen for capital in explaining TFP or TFP in explaining capital. The second, and third columns report the calculated values of the χ_m^2 test statistics for the significance of increasingly longer lags of capital in explaining TFP and the significance of increasing lags of TFP in explaining capital, respectively.

Table 4.4: χ_m^2 Granger Causality Test between TFP and Capital (K1) Investment

Number of lags	Capital (K1) causes TFP	TFP causes Capital (K2)
1	5.59**	0.85
2	5.46*	4.58
3	9.58**	6.52*

Note: *, **, denote 10 and 2.5% significance levels, respectively.

The result shows that with one lag of TFP and one lag of capital, the test statistic of 5.59 suggests that one lag of capital is significant at the 2.5% significance level, and that capital is Granger prior to TFP. However, with two lags the calculated value is significant at the 10% level. From three lags onward, capital causes TFP at all the significant levels.

The last column shows that with the third lag, TFP is significant at the 10% level for all the size classes, and can be said to be Granger prior to capital.[10] However, from the fourth lag TFP is Granger prior to capital at all the significance levels.

[10] If we look at the causal relationship between TFP and capital among the different size classes, then Table A4 (in Appendix II) suggests that size classes I and II which are the representative of smaller size classes have short lag relationships from TFP to capital. The results show that with one lag TFP is significant at the 10% level in the size classes I and II. However, with two lags size class III is significant at the 2.5% level and with the third lag size class IV is significant at the 10% level.

The above discussion on the causality tests between TFP and capital suggests a two-way causality from capital investment to productivity growth. However, Oniki (2001) found a one-way causality from capital investment to TFP for Japanese rice production. He used a time series based econometric analysis and single output.

Table 4.5, where capital consists of machinery and other inputs, shows the same result as in Table 4.4. Here, capital causes TFP with one lag length at the 5% significance level, and TFP causes capital with three lags at the 10% level.

Table 4.5: χ_m^2 Granger Causality Test between TFP and Capital (K2) Investment

Number of lags	Capital (K1) causes TFP	TFP causes Capital (K2)
1	4.99**	0.81
2	5.22*	4.51
3	10.25***	6.73*

Note: *, **, *** denote 10, 5, and 2.5% significance levels, respectively

The reason for showing the same result in Tables 4.4 and 4.5, in spite of different capital formulation, might be because land plays the role of a fixed input in Japanese agriculture. Land, like other capital inputs, did not grow in quantity over the years.

In some studies on Japanese agriculture (e.g. Lee and Kuroda, 2001), land has been treated as a fixed input since the land rent[11] during the postwar years was set at a certain low level by the government and therefore not a market price until at least 1975.

[11] In order to estimate land cost, the land price was first obtained by dividing land rent by the rented land area (1,000 yen per 10 area). This price was then used to impute the land cost of owned arable land area. Finally, the land cost was defined as the sum of total rent for owned and rented arable land and expenditures on land improvements and water use.

4.5 Conclusion and Policy Measures

This paper has measured agricultural productivity, and examined the causality between productivity and capital investment in Japanese agriculture for the 1957-97 period. We have found that the rates of growth of total output, total input, and TFP are different among the size classes. Table 4.1 shows that the total average growth rates of total output, total input, and TFP were 1.01, 0.15, and 0.86%, respectively.

In the second part of the study, this paper tested the causal relationship between TFP and capital using data on Japanese agriculture over the period 1957-97. The approach used was for Granger tests of causality between the two variables. This study explored whether productivity increases lead to capital investment or whether capital investment allows greater productivity.

The results of the tests suggest that there has been a significant and positive Granger-causal relationship running from TFP to capital as well as from capital to TFP in Japanese agriculture over the long term. We found capital causes TFP after one lag, and TFP causes capital with three lags.

The results found in this paper corroborate other studies, such as, Schimmelpfennig and Thirtle (1994), and Pardey and Craig (1989). However, they used R&D instead of capital for ten European countries and the USA. Moreover, Oniki (2001), by using time series based econometric analysis and single output (rice), found unidirectional causality from capital investment to TFP for Japanese rice production.

We used two models for capital (with and without land) to test causality with TFP and found consistent results with both the model. This indicates that land plays a fixed input role in Japanese agriculture. Land did not grow in quantity over the years like other forms of capital.

An important policy implication of the result of this study suggests that the government should encourage, in particular, large scale farming in order to increase total output and productivity. Causality test suggests that capital investment has been successful in increasing TFP and, capital investment tends to be forthcoming but it takes time for the larger size classes (size classes III and IV). Policy makers would require a very fast response for the short lag relationship from TFP to capital, and therefore, it is suggested that volume of capital investment need to be increased for the larger size classes to increase productivity in Japanese agriculture.

Although Oniki (2001) pointed out that unlimited improvement in productivity through capital intensification is not feasible, as capital-based innovation becomes more difficult over time, his study was limited to single output, whereas this study uses aggregated output. Therefore, further study may be needed to identify the exact ratio of capital investment to increasing productivity in the long-run. Till then, this study suggests increasing capital investment for the larger size classes to improve productivity.

Chapter 5

Summary and Conclusion

5.1 Main Contribution

Using modern technique to estimate the regional productivity in Bangladesh agriculture, we estimated the Malmquist productivity index, and later found that divergences among the regions disappear. Our causality tests on Japanese agriculture confirm the learning-by-doing process, and found a bi-directional causality between capital investment and productivity. Further, we suggested increasing the volume of capital investment in Japanese agriculture to improve the productivity growth.

5.2 Summary of the Thesis

The growth in agricultural productivity has slowed down substantially in the recent times. The inequalities at regional level increased which obstructed the balanced growth in the regional development. For the overall growth in the economy and sustainability in the agricultural productivity growth, the main issues are: to acknowledge the regional disparities, information on the direction of dispersion in agricultural productivity among the regions, and guidelines on the appropriate measures to improve the productivity growth.

In the light of the current issues in agriculture discussed above, here, in this thesis, we thoroughly investigated the agricultural productivity, convergence in agriculture, and the causal relationship between capital investment and productivity to confirm the learning-by-doing process. We used two different data sets for the estimations in Bangladesh and Japanese agriculture.

Our objective in this thesis has been to analyze the agricultural productivity at regional level and determine the pattern of the change in the productivity, the long-run trend towards convergence across districts, and investigate the long-run relationship between productivity and the variables that explain productivity. Our analysis indicates that significant differences in the productivity growth exist across the different district. However, there is evidence of long-run convergence in agricultural productivity. Further, the study found that capital causing TFP after one lag and TFP causing capital with three lags which suggests that capital investment has been successful in increasing TFP and capital investment tends to be forthcoming but it takes time for the larger size classes.

5.3 Policy Implications

Several important policies can be drawn from this study. The major policy is the need to increase the growth of productivity in Bangladesh agriculture. As we see, during the study period efficiency decreased substantially which 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. The policy implication is that Bangladesh needs to address the cause of the drastic fall in efficiency in the agricultural sector.

The policy of choosing the model districts and a strategy to make available the knowledge of the model districts to the lagged behind districts in productivity will help to reduce the inequalities among the districts, and further it will play a role in the overall regional development.

Our positive findings on convergence in agricultural productivity may lead to further investigation on whether the slowing down of the most productive districts caused convergence instead of catching-up of the less productive districts.

Another important policy implication from the study on causality suggests that the government should encourage, in particular, large scale farming in order to increase total output and productivity. Policy makers would require a very fast response for the short lag relationship from TFP to capital, and therefore, it is suggested that volume of capital investment need to be increased for the larger size classes to increase productivity in Japanese agriculture.

Appendices

Appendix I:

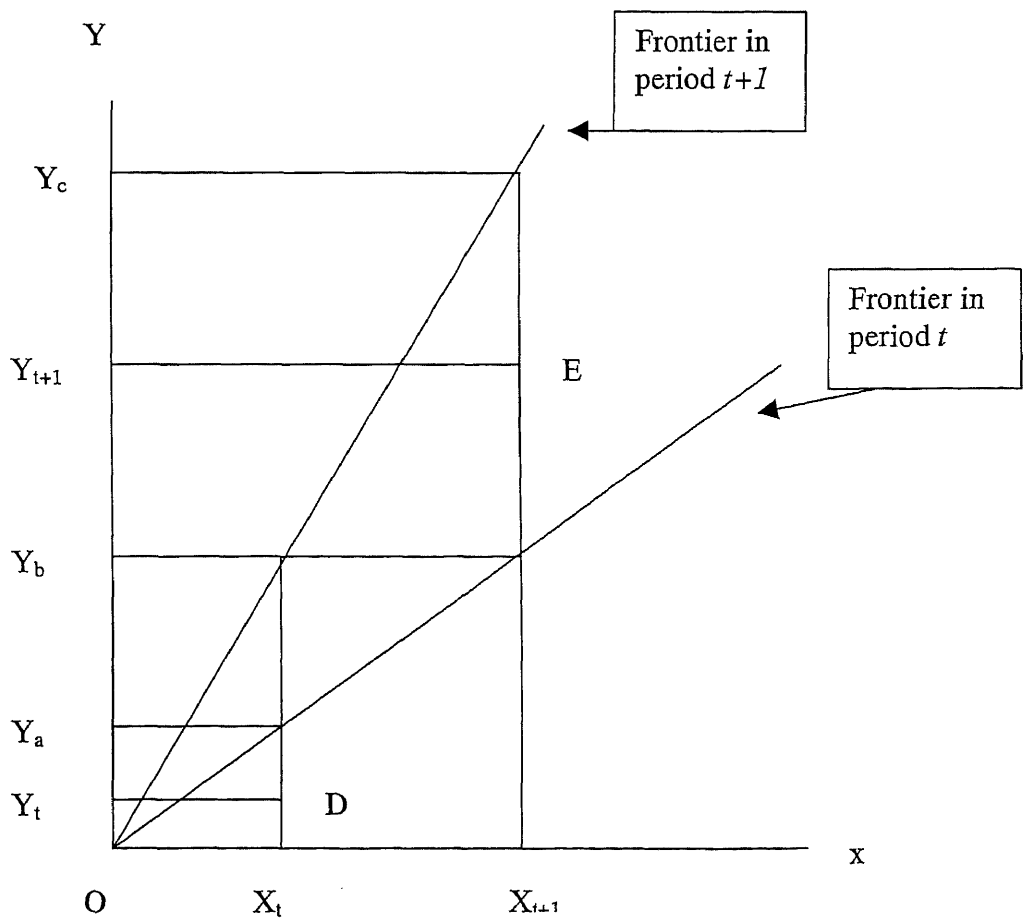
We have depicted a constant returns to scale technology involving single input and single output in the following diagram. The firm produces at the point D and E in periods t and t+1. In each period the firm is operating below the technology for that period. Hence, there is technical inefficiency in both periods. Using equations 2.4,

Efficiency change $= \dfrac{y_{t+1}/y_C}{y_t/y_a}$, and Technical change $= \left[\dfrac{y_{t+1}/y_b}{y_{t+1}/y_c} X \dfrac{y_t/y_a}{y_t/y_b}\right]^{1/2}$

Therefore, the Malmquist productivity index can be written as,

$$m_o = \left(\frac{y_{t+1}/y_C}{y_t/y_a}\right)\left[\frac{y_{t+1}/y_b}{y_{t+1}/y_c} X \frac{y_t/y_a}{y_t/y_b}\right]^{1/2} .$$

A value of M_o greater than one will indicate positive TFP growth from period t to period t+1 while a value less than one indicates a TFP decline.



Appendix II:

Table A1: Total Agricultural Production as Percentage of GDP at Constant (1984-85) Price

Year	Total Agricultural production as percentage of GDP
1979-80	47.6
1980-81	45.5
1981-82	48.71
1982-83	49.24
1983-84	48.00
1984-85	41.75
1985-86	41.37
1986-87	40.00
1987-88	38.73
1988-89	38.15
1989-90	37.75
1990-91	37.60
1991-92	36.86
1992-93	35.92
1993-94	34.58
1994-95	32.77
1995-96	32.24
1996-97	32.41
1997-98	31.58
1998-99	31.55

Table A2: Technical Efficiency Change, Technical Change and Productivity levels by Districts at the beginning of the study period, 1980.

Districts	Technical efficiency change (TEC)	Technical change (TC)	Productivity (MFP)
Dinajpur	1.004	1.390	1.396
Ranjpur	1.000	0.935	0.935
Bogra	1.000	1.175	1.175
Rajshahi	1.040	1.068	1.110
Pabna	1.000	0.994	0.994
Kushtia	1.000	1.279	1.279
Jessore	0.965	1.046	1.009
Khulna	0.964	0.800	0.772
Barisal	2.297	0.992	2.279
Patuakhali	1.000	1.656	1.656
Mymensingh	0.998	1.037	1.035
Jamalpur	1.000	1.029	1.029
Tangail	1.012	1.088	1.100
Dhaka	1.064	0.955	1.016
Faridpur	1.000	0.919	0.916
Sylhet	1.000	1.202	1.202
Comilla	1.257	1.089	1.369
Noakhali	1.000	0.713	0.713
Chittagong	1.000	1.036	1.036
Chit. H. T.	1.000	0.999	0.999

Table A3: Growth Rates of TFP among size classes

Year\Size Class	(I)	(II)	(III)	(IV)	Average
1957-1971	2.0232	1.7036	1.3691	0.9891	1.5215
1972-1984	-0.1995	0.1141	0.3200	0.4877	0.1805
1985-1997	0.0324	-0.2795	0.3185	0.3945	0.1164
1957-1997	0.7613	0.8590	0.9152	0.9010	0.8591

Table A4: Granger Causality Test between TFP and Capital (K1) Investment among Size Classes (TFP causes Capital)

No of Lags	Size Class I	Size Class II	Size Class III	Size Class IV	All Size Classes
1	2.83*	3.06*	0.72	1.95	0.85
2	9.75***	9.64***	8.10***	4.18	4.58
3	14.09***	16.69***	6.99*	7.48*	6.52*

Note: *, **, *** denote 10, 5, 2.5% significance levels, respectively.

Appendix III:

Figure A1: Productivity Growth Rates for the Selected Districts

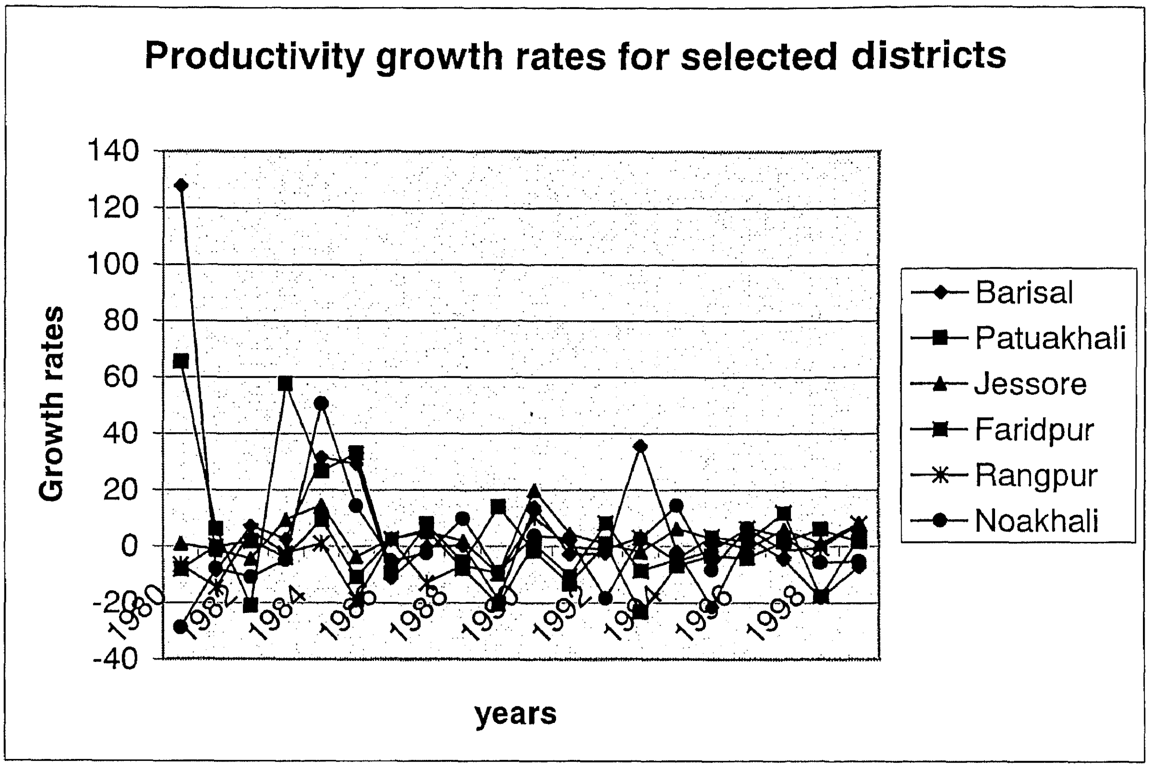


Figure A2: Index of capital (K1) in all size classes

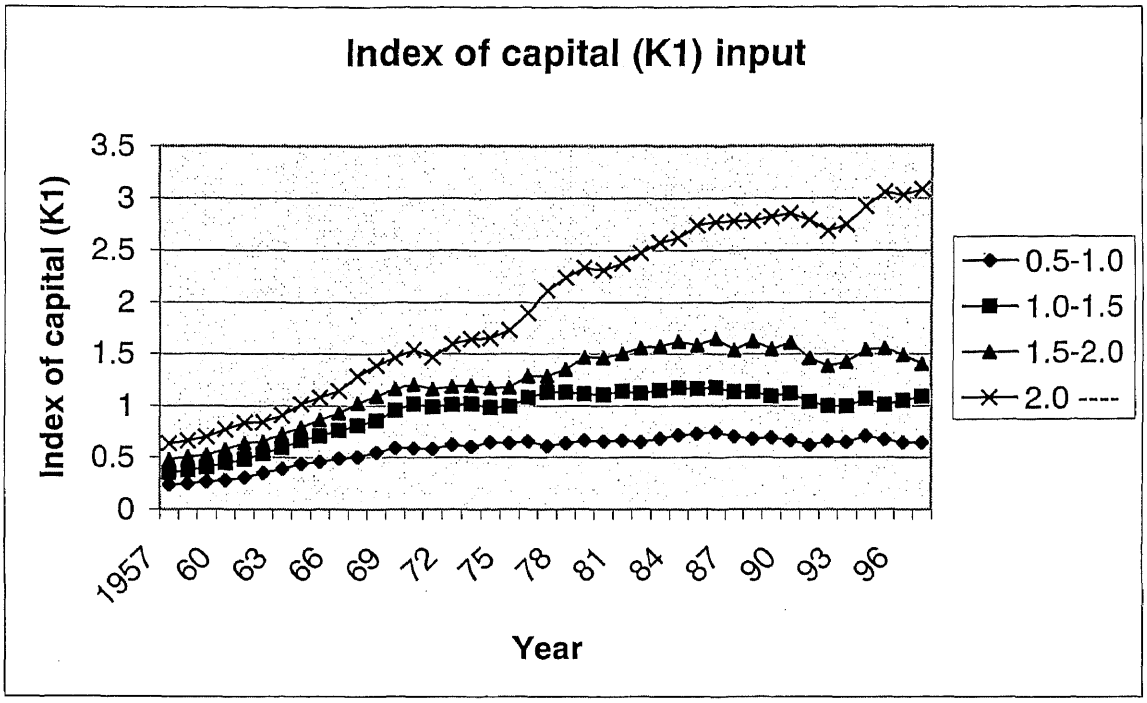
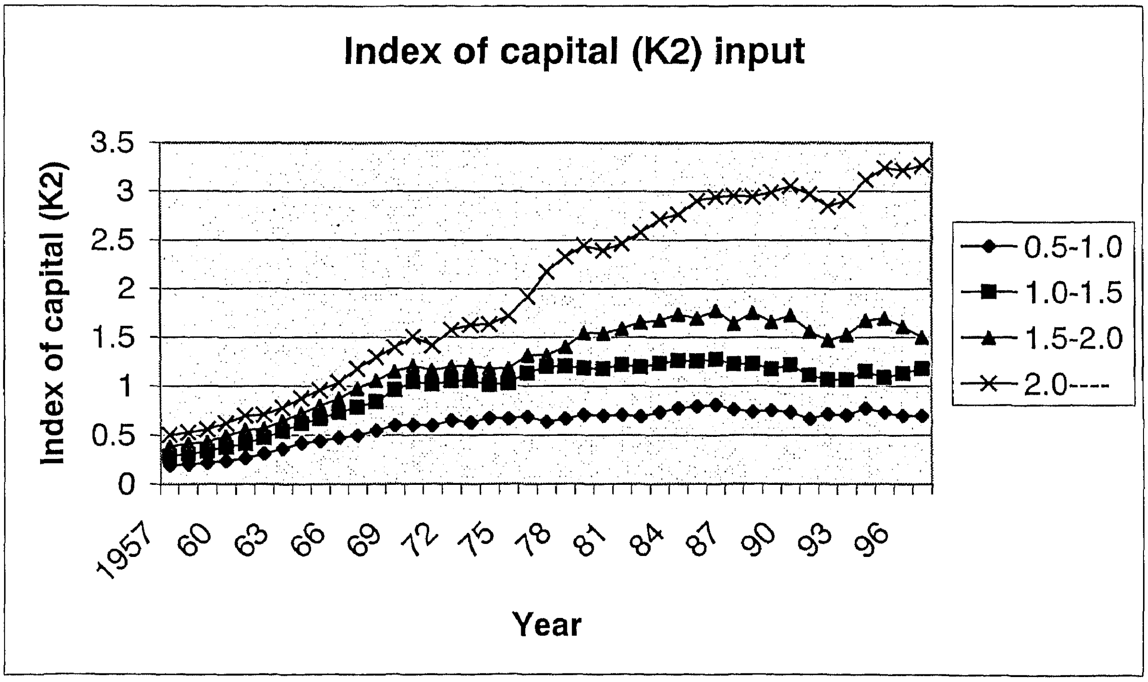


Figure A3: Index of capital (K2) in all size classes



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