Department of Economics PhD Thesis

2001

An Empirical Study of Factor Substitution in Bangladesh Agriculture

Raihana, Bilkis
University of Rajshahi

AN EMPIRICAL STUDY OF FACTOR SUBSTITUTION IN BANGLADESH AGRICULTURE

A THESIS SUBMITTED TO THE UNIVERSITY OF RAJSHAHI FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN ECONOMICS

By

BILKIS RAIHANA

Department of Economics

Rajshahi University

November, 2001

CERTIFICATE

The undersigned certifies that the thesis entitled "An Empirical Study of Factor Substitution in Bangladesh Agriculture" submitted to the University of Rajshahi for the award of the Doctor of Philosophy degree in Economics is an original work done by Bilkis Raihana.

Tariq Saiful Islam

Tariq Saiful Islam
Supervisor
and
Professor
Department of Economics
University of Rajshahi

Date : November 28, 2001

DEDICATION

To the memory of my father
late Md. Badrul Haque

DECLARATION

I do hereby declare that this thesis entitled "An Empirical Study of Factor Substitution in Bangladesh Agriculture" submitted to the University of Rajshahi is an original work and it has not been submitted to any other University or Institution for award of any degree.

Bilkis Raihana

Bilkis Raihana

ACKNOWLEDGMENT

I am very much indebted to my supervisor Professor Tariq Saiful Islam for his guidance, suggestions and encouragement during my research work. The research work leading to this doctoral dissertation would not have been possible without his patience and constructive advice.

I would also like to express my gratefulness to Professor Ahsanul Habib, Department of Economics, Rajshahi University (now at the Central Bank of Kuwait). I would also like to express my thanks to Abdullah Shams Bin Tariq for his help in some estimation work.

I am thankful to the Department of Economics, Rajshahi University for extending all cooperation during my research work. I am also thankful to my teachers for their help and encouragement.

I was encouraged by my parents to undertake this research study and I acknowledge my special indebtedness to them. I am grateful to my husband for his constant inspiration and encouragement and to my daughter Shifa and son Rasha for their pleasant presence.

ABSTRACT

This study is concerned with factor substitution, technical change and productivity change in Bangladesh agriculture. The translog cost function is used to study both substitutability and complementarity relationships between inputs. In analyzing the changes in productivity, the Divisia indexing method which has a flexible weighting scheme is used.

Using both homothetic and nonhomothetic structure, the Allen partial elasticities of substitution (AES) estimated to examine the nature of factor substitution among the four inputs of land, labour, fertilizer, and irrigation covering the period from 1973 to 1995. The responsiveness of input demand to input prices is explored by estimating own price and cross price elasticities of demand. The empirical estimates indicate the existence of both substitutability and complementarity among inputs. The nonhomotheetic structure with technical change clearly characterized the Bangladesh agricultural sector. A very high degree of substitutability between fertilizer and irrigation was found in both the homothetic and nonhomothetic structures. The empirical estimates showed evidence of land and labour saving technical changes and presence of fertilizer and irrigation using technical changes during the study period.

Using the Tornqvist approximation to the Divisia index, total factor productivity was estimated. Total factor productivity (TFP) in Bangladesh agriculture

increased at an annual growth rate of 1.69 percent during the period from 1973 to 1995. During the same period, the terms of trade (ratio of output and input prices) deteriorated at an annual rate of 1.19 percent.

By considering the farmers' terms of trade and returns to costs (ratio of value of output and value of input), the distribution of productivity gain was also studied. The growth rate of returns to costs was 0.50 percent which implied that farmers' economic condition slightly improved over the period from 1973 to 1995.

CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure **Title** **Page**

CHAPTER 1

INTRODUCTION

The objective of this research is to conduct an empirical study of factor substitution and technical change in Bangladesh agriculture. This is an aggregate time series study covering the period of 1973 to 1995. These aspects of Bangladesh agriculture will be studied using a production function approach. Following the developments in recent years, the flexible functional forms are used to study the production structure. Based on this approach, substitutability and complementarity between inputs are studied and the nature of technical change and input demand are examined. In the study of productivity, appropriate indexing method is used and productivity growth estimated.

1.1 The Issue

Thirty years have elapsed since the emergence of Bangladesh as an independent nation in 1971. It is now possible to undertake a meaningful time series empirical study of Bangladesh agriculture. There has been significant change in the relative importance of different agricultural inputs in Bangladesh. There are important changes in input mix due to introduction of modern technology and changes in relative factor prices in the agriculture sector of Bangladesh. In this study, an attempt is made to see whether labour has been substituted by non-durable inputs such as fertilizer and irrigation. This study also examines the presence of input-augmenting technical change and the role of fertilizer and irrigation in Bangladesh agriculture. The extent of factor substitution in Bangladesh agriculture is estimated using the translog cost function. Corresponding to the modifications of the translog cost function, derived demand function is used to obtain measures of elasticity of demand for four inputs.

In Bangladesh, there is a rapid transformation in the crop sector due to adoption of irrigation-fertilizer technology. This study attempts to see whether productivity growth has increased over time. The distribution of productivity gains is also studied to see whether farmers' welfare has improved. Total factor productivity is estimated by using the flexible-weight Divisia indexing procedure and its well-known Tornqvist discrete approximation. The Divisia indexing procedure is different from the widely used fixed-weight Laspeyres index and has been recommended, among others, by Christensen (1975), and the United States Department of Agriculture (USDA, 1980) for productivity measurement.

1.2 Research Objectives

The core objectives of the present study are listed below:

- Analysis of the nature of factor substitution. Using the concept of Allen partial elasticities of substitution, the substitutability and complementarity relationship between different factors are examined.
- Investigation of the responsiveness of input demand to input prices by estimating own price and cross price elasticities of demand.
- Analysis of the nature of technical change.
- Estimation of growth rates in productivity applying the total factor productivity concepts and flexible-weight Divisia indexing method.

- Analysis of the distribution of productivity gains in agriculture using the estimates of changes in farmers' terms of trade and returns to costs ratio.

1.3 Methodology

The Theoretical Model

This study is concerned with the empirical estimation of factor substitution and technical change. This estimation is done using the transcendental logarithmic (translog) function. It is well-known that *a priori* fixed production functions such as the Leontief, the Cobb-Douglas and the CES place restrictive constraints on factor substitution. For the Leontief function, the value of elasticity of substitution is zero and for the Cobb-Douglas function it is equal to unity. The CES function made a major advance in factor substitution study by allowing factor substitution of different magnitudes (0 to + ∞). But this production function cannot be used to study complementarity which is an important characteristic of agricultural production.

The family of production functions which can generate any magnitude of factor substitutions (- ∞ to + ∞) is known as flexible forms. The most well-known and widely used of these is the translog function. Since this functional form allows study of factor substitution of different magnitudes as well as the nature of technical change, it has been chosen for this study.

Input Classification and Time Period

Input classification is made to examine the role of both durable and non-durable inputs. In this study, four inputs of land, labour, fertilizer, and irrigation are considered. Land and labour represent primary inputs. In case of Bangladesh, the use of energy in the cultivation process is not significant. Energy is mostly used in irrigation and as such energy has not been treated as a separate input. Agriculture sector is considered as a whole in this study which covers the period of 1972-73 to 1994-95.

Estimation Procedures

To find the indicators of production structure, econometric estimation of the derived demand equations using a simultaneous approach is done. Since changes in the prices of inputs induce changes in the use of inputs, it is necessary to study the entire spectrum of simultaneous changes to explain substitutability and complementarity relationship between inputs. When all prices are treated as exogenous, an appropriate econometric approach is Zellner's Seemingly Unrelated Regression technique (Zellner, 1962), often referred to as SUR. When exogeneity of explanatory variables is in question, the Three Stage Least Squares (3SLS) and the Full Information Maximum Likelihood (FIML) are used. In this study, the FIML has been used, the rationale of which is elaborated in Chapter 4.

Divisia indexing method is considered appropriate for the translog function (Christensen, 1975; Diewert, 1976). Divisia indexing method is used in this study for constructing the relevant input and output indexes. This procedure can accommodate flexibility of the translog function.

1.4 The Plan of the Study

This thesis consists of eight chapters. The introductory chapter is Chapter 1. It provides a brief description of the objectives, models, input classification and estimation techniques of this study. Chapter 2 presents the nature of input use in Bangladesh agriculture. Chapter 3 provides a brief survey of earlier flexible form studies, while Chapter 4 contains the theoretical model of factor substitution, input classification, and estimation techniques used in this study. Chapter 5 is devoted to the data and their modifications. Chapter 6 contains the empirical estimation of factor substitution, factor demand and the nature of technical change. In Chapter 7 the estimates of total factor productivity and the distribution of productivity gains are presented and examined. Finally, Chapter 8 contains the summary, policy implications and conclusions of this study.

CHAPTER 2

INPUT USE AND OUTPUT GROWTH IN BANGLADESH AGRICULTURE

A descriptive picture of changes in input use and output growth in Bangladesh agriculture is given in this chapter. The description of input use follows the input classification used in this study. Main inputs are classified as land, labour, fertilizer, and irrigation. In Bangladesh, agricultural output consists of crop and non crop agriculture. Due to dominant role of crop agriculture, it is considered as agricultural output in this study. The input use and the performance of agricultural output may provide a clear picture of production activity in Bangladesh agriculture.

Bangladesh is predominantly an agricultural country. All important activities depend on the agricultural sector. Since independence, though the relative importance of agriculture sector has decreased in terms of the share of GDP (gross domestic products), it still accounted for 30.88 percent of the nation's GDP at current prices in 1994-95. In the post independence period, a rapid expansion of irrigation, fertilizer and modern variety (MV) seeds caused a breakthrough in Bangladesh agriculture and Bangladesh made steady progress in crop production.

2.1 Main Inputs

Land

Land is the main source of all agricultural activities. As an agrarian economic base, land occupies a dominant position in the Bangladesh agricultural sector. Since independence, like other inputs, the use of land changed substantially over time. A comparative land utilization statistics in Bangladesh for 1974 and 1990 is shown in Table 2.1.

Table 2.1: Comparative Land Utilization in Bangladesh, 1974 and 1990

Land Use	Area (in thousand hectares)	
	1974	1990
Cultivated Cropland (net)	8489	8837
Forest	2229	1858
Cultivable Waste	272	267
Current fallow	627	288
Not available for cultivation	2661	3934
Total land area	14278	15184

Source: Khalil, I. (1991), *The Agricultural Sector in Bangladesh: A Data Base*, Dhaka: US Agency for International Development, p.32.

From Table 2.1 it is observed that total land area increased over time and net cultivated cropland increased moderately between 1974 and 1990. In 1974, the net cultivated cropland was 8489 thousand hectares, which increased to 8837 thousand hectares by 1990. Besides this, Table 2.1 also indicates that the forest, cultivable waste and current fallow land decreased while area, not available for cultivation, increased in 1990 relative to 1974. Here cultivable waste means the area suitable for cultivation but lying idle more than one year and current fallow implies area brought under cultivation but not cultivated during the year.

In Bangladesh, landholdings are fragmented largely because of high growth of population and lack of employment opportunities in non-agricultural sector. Besides this, the Islamic laws of property inheritance are responsible for continued fragmentation of land holdings which have often split the land into very small plots.

In Bangladesh, the pattern of land ownership is skewed and this trend is aggravating. The skewness in the distribution of land ownership occurred due to famines and natural calamities like flood, cyclone and drought. In this situation, small farmers are compelled to sell their land, causing thereby an increasing fragmentation of land holdings. But due to adoption of traditional technology they are unable to increase their income as a subsistence occupation. Mostly, the small farmers cultivate land as wage labourers and, in a dull agricultural season, they are also engaged in non-farm activities.

Bangladesh agriculture has witnessed changes in the patterns of land utilization. Table 2.2 exhibits the patterns of land utilization in Bangladesh. From this table it is seen that area not available for cultivation increased over time due to gradual increase of urban and rural settlements, market places, roads, canals and water bodies. Culturable waste and area sown more than once increased gradually and net cropped area increased steadily from 1972-73 to 1986-87. But from 1987-88, it started to decline. Current fallows also decreased over time. It was found that, total cropped area was 29039 thousand acres in 1972-73 which increased to 33413 thousand acres in 1994-95.

Total cropped area in Bangladesh is graphically shown in Figure 2.1. From this figure, it is observed that a slow increasing tendency was found for the total cropped area in Bangladesh while the curve for the last two years showed a declining tendency. This may have been caused by the natural disasters. In 1993-94

Table 2.2 : Patterns of Land Utilization in Bangladesh, 1972-73 to 1994-95

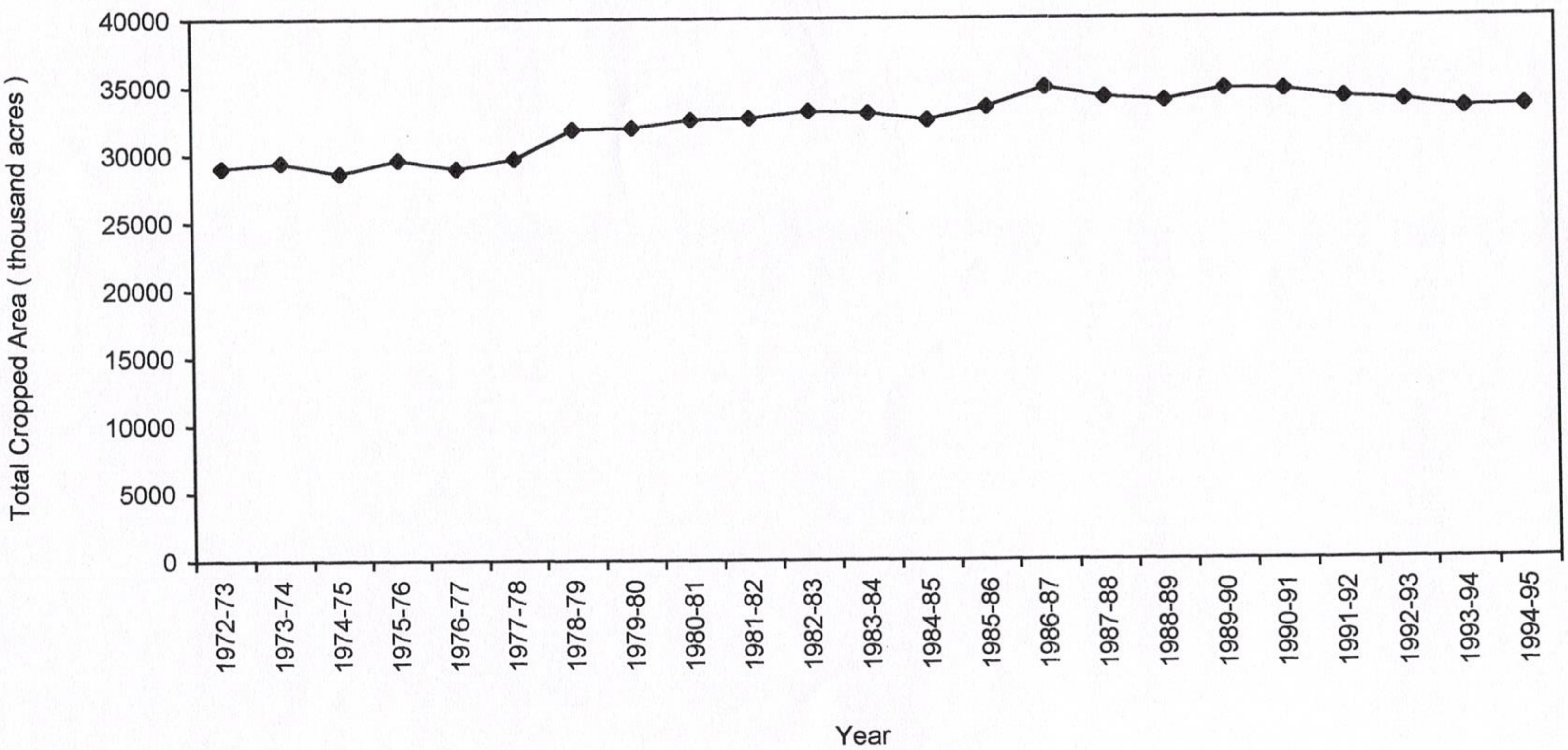
(in thousand acres)

Year	Not available for cultivation	Culturable waste[1]	Current fallows[2]	Net cropped area	Area sown more than once	Total cropped area[3]
1972-73	6572	681	1679	20840	8199	29039
1973-74	6575	672	1550	20977	8447	29425
1974-75	6576	670	2009	20559	8078	28637
1975-76	6622	662	1591	20968	8718	29636
1976-77	6626	661	2100	20445	8534	28979
1977-78	6669	665	1838	20693	9009	29702
1978-79	6674	623	1760	20801	11045	31816
1979-80	6686	615	1705	20873	11100	31973
1980-81	6712	619	1404	21158	11363	32521
1981-82	6837	611	1350	21212	11426	32638
1982-83	6876	572	1196	21369	11761	33130
1983-84	7156	810	1124	21442	11571	33013
1984-85	7193	721	1221	21355	11143	32496
1985-86	7220	670	997	21661	11798	33459
1986-87	7921	652	961	21878	13005	34883
1987-88	7685	890	2913	20478	13678	34148
1988-89	7645	888	3285	20148	13739	33887
1989-90	7783	863	2686	20633	14117	34750
1990-91	7958	1442	2379	20193	14482	34680
1991-92	9885	1532	862	19716	14405	34121
1992-93	10137	1512	928	19418	14438	33856
1993-94	10355	1566	984	19090	14225	33315
1994-95	10128	1547	1000	19133	14280	33413

[1]Culturable waste = The area suitable for cultivation but lying fallow for more than one year.
[2]Current fallows =The area already brought under cultivation, but not cultivated during the year.
[3]Total cropped area =Sum of the net cropped area and the area sown more than once.

Source: *Statistical Yearbook of Bangladesh* (Various issues), Dhaka: Bangladesh Bureau of Statistics.

Figure 2.1: Total Cropped Area in Bangladesh, 1972-73 to 1994-95



and 1994-95, food grain production declined due to depressed prices of rice and natural disasters particularly floods, and droughts in the north-west region of the country. During these years, more than 2 percent reduction in area sown was also observed (GOB, 1998).

Increased food production depends on proper cultivation and land utilization. Land utilization includes both the cultivated and uncultivated areas of farm holdings. Farm holding means an agricultural production unit where practically the entire household is engaged and consists of livestock and land utilized for agricultural production under a single management. It may be managed by a person or with others. It is found that while total cultivated area of farm holdings has increased over time per capita cultivated land has gradually decreased as a result of increase in population and number of farms (BBS, 1989).

Labour

Agriculture is the largest employer of labour. As a primary sector in the economy, agriculture provides the source of income. In past, the crop sector generated most of the employment opportunities in the agriculture sector. Over time, importance of labour in the crop sector has been gradually decreasing. Since smaller farms need fewer hired workers, the continuing fragmentation of land holdings and resultant proliferation of smaller farms have tended to decrease the overall demand for agriculture labour.

According to various censuses, it is observed that the participation of labour force in the agriculture sector has declined whereas in the non-agriculture sector this showed an increase. Table 2.3 shows the present nature of employment.

Table 2.3 : Distribution of Economically Active Population by Sex and by Major Occupation Groups in Bangladesh, 1961-1991, Census Years

(in percent)

Year	Sex	Major Occupation	
		Agriculture	Other
1961	Both sex	86.0	14.0
	Male	85.0	15.0
	Female	91.8	8.2
1974	Both sex	77.2	22.8
	Male	77.5	22.5
	Female	69.8	30.2
1981	Both sex	61.3	38.7
	Male	63.0	37.0
	Female	28.0	72.0
1991	Both sex	54.6	45.4
	Male	57.5	42.5
	Female	18.0	82.0

Source: BBS (1994), *Bangladesh Population Census,* National Series, Vol. I, Dhaka: Bangladesh Bureau of Statistics.

It can be seen from Table 2.3 that in 1974, 77.2 percent of the labour force engaged themselves in the traditional agriculture while the remaining 22.8 percent were engaged in non-agricultural activities. But in 1991 the occupational dependence in agriculture sector declined. This happened due to the transfer of agricultural labour force from the traditional agriculture sector to the non-agriculture sector. It should be noted that household-based economic activities were excluded in these censuses. The household activities consist of threshing, cleaning and processing of food grains, care of livestock, poultry, etc. which are mostly done by the females.

It is interesting to note that women also play a significant role in this sector. The major portion of rural women largely appear as unrecognized contributors to the agriculture sector and other economic activities. In Bangladesh, as a subsistence family occupation, women used to be involved in post-harvest work by using the *dheki* (one type of foot-operated morter and pestle which is used for husking, grinding, etc. of food grains). But after the introduction of mechanized husking and polishing of grains men are now engaged in these operations in modern mills. About the participation of women in the agriculture sector, the *World Development Report 1990* reported that emerging financial institutions like Grameen Bank also helped to grow the working women's forum in Bangladesh. This report showed how the working women used the loans of Grameen Bank which helped greater participation of women in the agriculture sector.

According to the *Labour Force Survey 1990-91,* number of agricultural labour forces (both sex) decreased to 34354 thousand from 37006 thousand in 1989. On the other hand, number of the labour forces (both sex) in the non-agricultural sector increased to 15804 thousand while it was 13141 thousand in 1989. As compared to the *Labour Force Survey 1989*, both male and female labour forces in the agricultural sector also decreased according to this survey.

In rural areas, major portion of non-farm households depends on agriculture due to lack of other sources of employment. Households having less than 0.05 acre of cultivated land are treated as non-farm households. Agriculture-labour households mean those households whose earnings come from labour services provided to the agriculture sector (BBS, 1989). In Bangladesh, members of agriculture labour households are often found to be engaged in auxiliary occupations such as livestock raising, poultry raising, cottage industry, fishing etc. as sources of subsidiary income.

Fertilizer

Fertilizer is of immense importance for sustained increase in crop production. Since independence, the use of chemical fertilizer has steadily increased. Due to large production and expanded marketing system, there has been a rapid expansion of fertilizer use in Bangladesh. In 1950, chemical fertilizers were first introduced in Bangladesh but significant use of chemical fertilizer was not found until 1960. At that time chemical fertilizer was mostly used in tea gardens and government experimental farms. Since then Bangladesh Agricultural Development Corporation (BADC) started to sell chemical fertilizers to the farmers.

The government initially gave subsidy to make fertilizer more popular to the farmers. Gradually this subsidy has been reduced. The government introduced a new marketing system in 1982, which deregulated retail trade in fertilizer. Due to withdrawal of explicit subsidy from the phosphate and potash fertilizers and handing over of their trade to the private sector, prices of these items increased. But in July 1994 and in early 1995, the price of urea was reduced (GOB, 1998).

With the introduction of HYVs of rice in Bangladesh, consumption of fertilizer went up sharply. Fertilizer is mostly applied on the *boro* crops under irrigated conditions. The July-October period is the fertilizer season for *aman* paddy while the various *rabi* crops like potato, wheat, mustard and sugarcane are associated with fertilizer from November to March. Fertilizer is used on the *aus* paddy and jute from April to June. In case of application rate of fertilizer, *boro* crops alone consume nearly 2.5 times more fertilizer than all crops combined. Since independence, an overall rise in fertilizer consumption is noted. The annual average growth rate was over 9 percent between 1969-70 and 1989-90 (GOB, 1990).

Of the various types of chemical fertilizers used in Bangladesh, urea is the most important followed by triple super phosphate (TSP) and muriate of potash (MP). Table 2.4 presents the consumption pattern of various types fertilizer in Bangladesh. A rapid transition in fertilizer consumption was observed during 1972-73 to 1994-95 period. In 1972-73, urea consumption was only 277 thousand metric tons while it rapidly increased to about 1746 thousand metric tons in 1994-95. Triple super phosphate (TSP) gradually rose up to 1990-91 and from 1991-92 it continued to fall till the last stage of the period, perhaps due to the introduction of SSP (single super phosphate) fertilizer. Muriate of potash (MP) also significantly increased during this period. The remarkable increase in consumption of fertilizers happened due to large domestic production, increased farm consumption and expanded marketing role. Besides these, government policies also played a major role in creating these developments.

Table 2.4: Fertilizer Consumption by Volume in Bangladesh, 1972-73 to 1994-95

(in thousand metric tons)

Year	Urea	Triple Super Phosphate (TSP)	Muriate of Potash (MP)
1972-73	277	89	18
1973-74	268	94	18
1974-75	176	76	18
1975-76	312	111	22
1976-77	353	126	22
1977-78	480	192	41
1978-79	471	178	47
1979-80	353	203	46
1980-81	560	215	45
1981-82	519	208	45
1982-83	619	203	50
1983-84	708	261	63
1984-85	832	346	69
1985-86	647	259	52
1986-87	841	311	68
1987-88	886	328	72
1988-89	1145	416	94
1989-90	1369	480	119
1990-91	1322	515	147
1991-92	1531	457	136
1992-93	1545	407	122
1993-94	1577	234	138
1994-95	1746	123	140

Source: *Statistical Yearbook of Bangladesh* (Various issues), Dhaka: Bangladesh Bureau of Statistics and Khalil, I. (1991), *The Agricultural sector in Bangladesh: A Data Base,* Dhaka: US Agency for International Development and estimated.

The consumption of urea in Bangladesh is graphically displayed in Figure 2.2.a. From this figure it is seen that consumption of urea increased markedly over time. Figure 2.2.b exhibits the consumption of TSP in Bangladesh. It is seen that the consumption of TSP increased gradually till 1990-91 and from 1991-92 the declining tendency set in. It happened due perhaps to the increasing consumption of another type phosphate fertilizer, called SSP (single super phosphate). Here the curve also showed extreme declining tendency of TSP in 1993-94 and 1994-95. Figure 2.2.c shows the consumption of MP in Bangladesh. This figure indicates that consumption of MP increased gradually till 1986-87 and then rapidly from 1987-88.

Irrigation

In Bangladesh, farmers largely depend on rainwater for cultivation with the result that any error from the optimum pattern of rainfall causes problems for agricultural production. This dependence on rainwater is gradually decreasing with the application of irrigation using modern technology. Before introduction of modern irrigation, farmers mostly used traditional methods like swing baskets and *dhones* for lifting surface water.

Since independence, use of irrigation water has been increasing and it should be regarded as the most modernized component of Bangladesh agriculture. Land utilization can be increased through irrigation. In recent years, vast programmes were undertaken by the government resulting in a rapid increase of irrigation. Effective flood control and drainage and minor irrigation on supplementary basis play a vital role in the extension of low-risk modern technology cropping. Minor irrigation consists of the traditional and modern manual technology. Among the modern technology motorized low lift pumps (LLPs), shallow tubewells (STWs), and deep tubewells (DTWs) are dominant.

Figure 2.2.a: Consumption of Urea in Bangladesh, 1972-73 to 1994-95

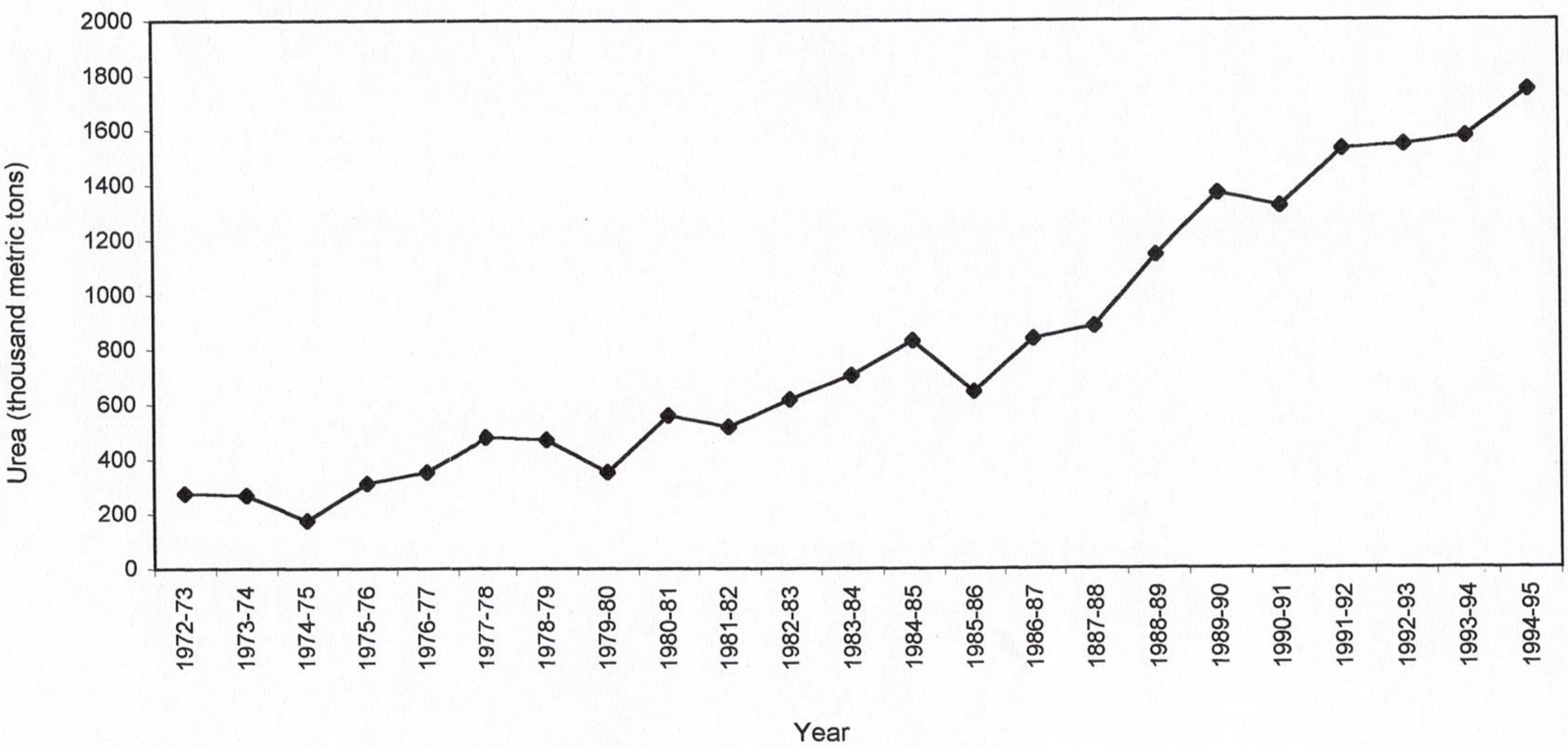


Figure 2.2.b: Consumption of TSP in Bangladesh, 1972-73 to 1994-95

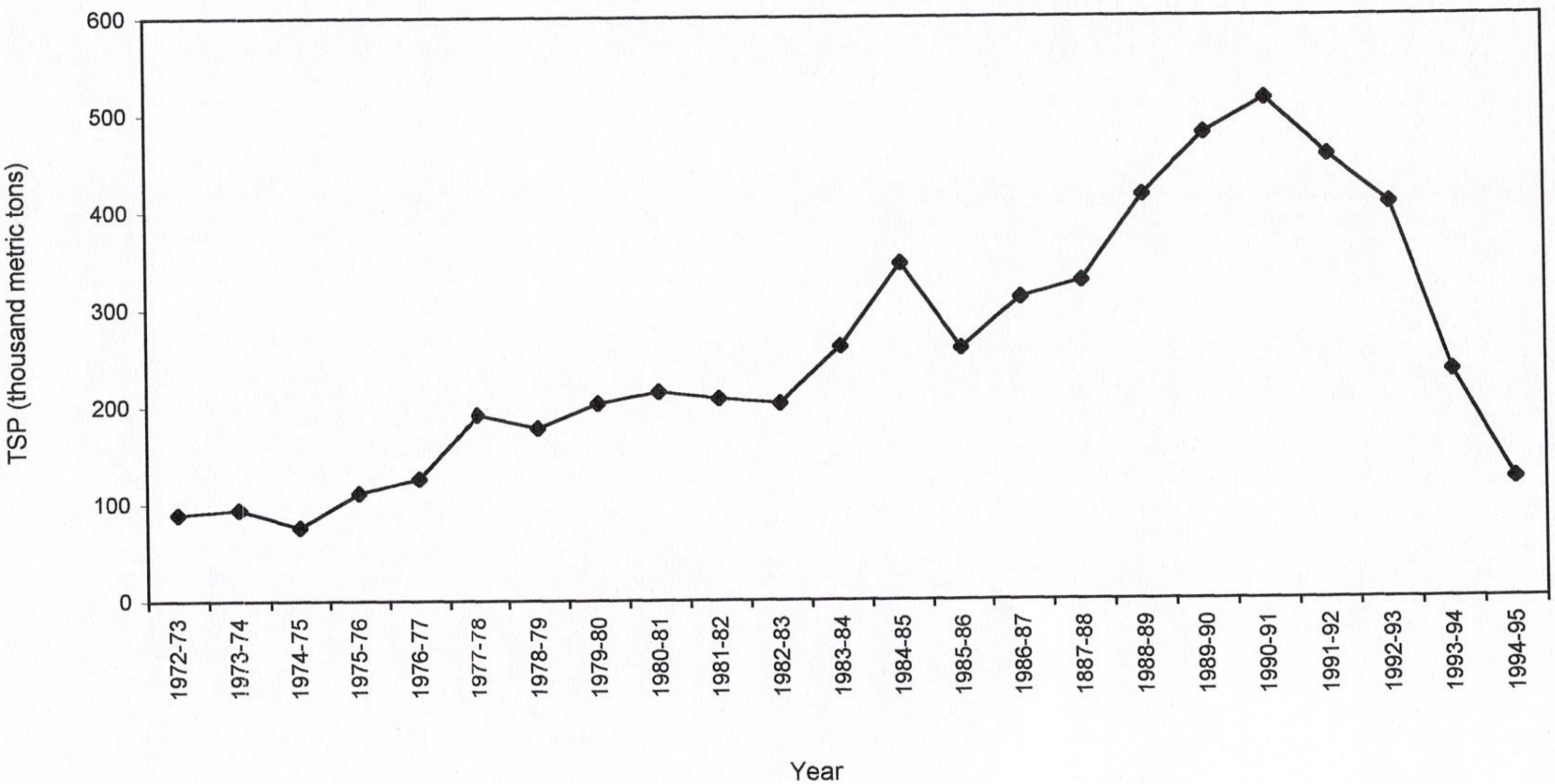
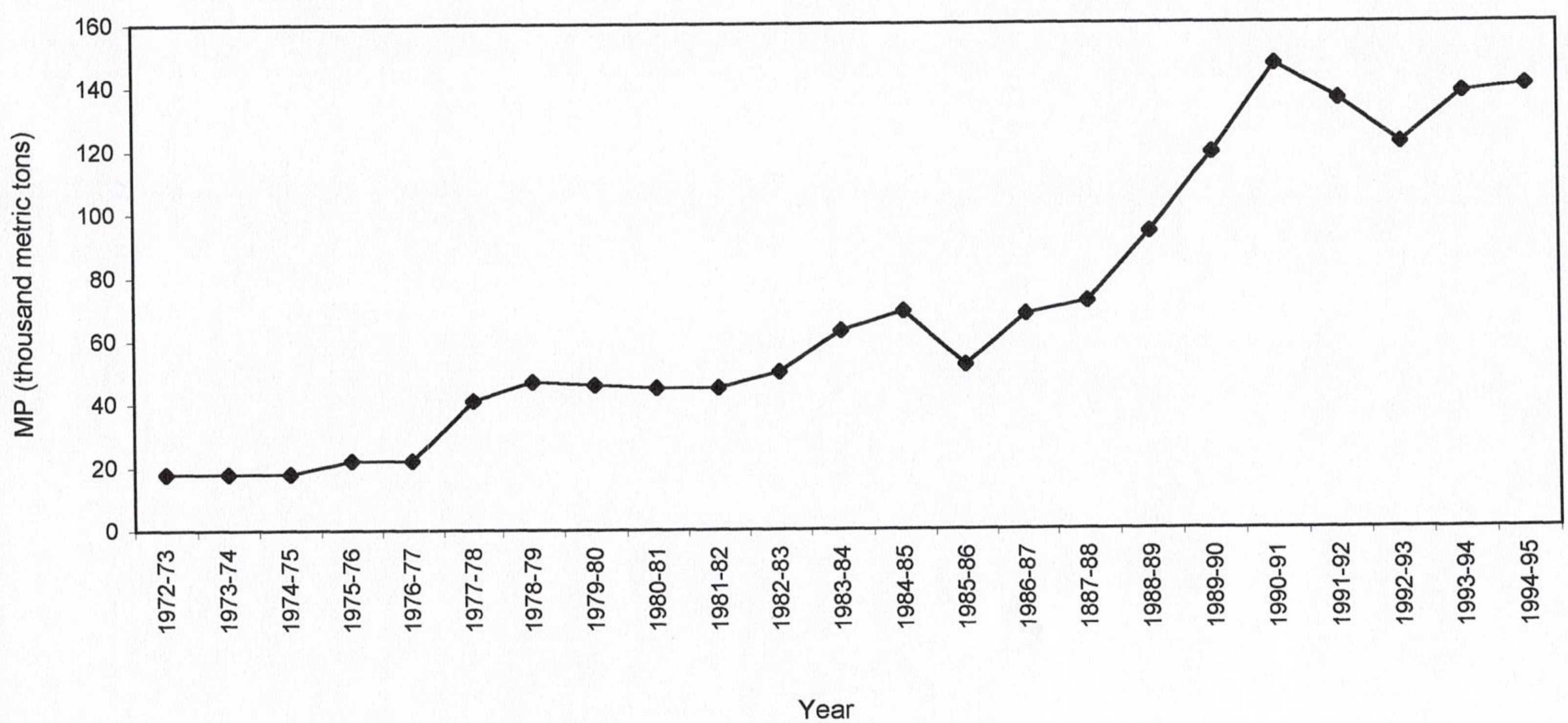


Figure 2.2.c: Consumption of MP in Bangladesh, 1972-73 to 1994-95



At present both traditional and modern methods of irrigation exist in Bangladesh. Among the traditional methods swing basket is dominant. As a primitive method, open *dugwell* is widely used, particularly in areas where water level is relatively higher. Among the modern systems, LLP, DTW, and STW are the most important ones. For the smal scale irrigation, hand tube well (HTW) is also used by the poor farmers. Bangladesh Agricultural Development Corporation (BADC) and Bangladesh Water Development Board (BWDB) mostly undertake major irrigation projects such as canal digging and DTWs.

The history of post-independence irrigation development can be divided into four phases. In the first phase, public sector LLPs and DTWs covered most of the irrigated area up to 1979. In the second phase, mainly STWs in the private sector liberally expanded from 1979 to 1989. In the third phase, from 1984 to 1987, expansion of irrigation was constrained by the limitations of STW operation in the private sector. Drop in the ground water level in many places where STWs operated and government-imposed embargo on diesel engines added to the administrative bottlenecks created by privatization. In the latest phase, starting from 1987, import bar on diesel engines has been removed and there has been rapid expansion in private sector sales of STWs and DTWs. From 1988-89, under the new policies, duties and standardization restriction of imported small diesel engines were removed (GOB, 1990). These helped to encourage the rapid expansion of private sales of STWs and LLPs. Since 1973-74, sale of STWs increased rapidly as it could be purchased with credit facilities available from Bangladesh Krishi Bank and its Rajshahi Division counterpart Rajshahi Krishi Unnayan Bank.

LLPs are used in areas where surface water is available. Area irrigated by LLPs has increased over time. To enable participation of the farmers in the canal digging programs, the objective was to supply pump sets free of cost to the participating farmers. The main objective of this scheme was to preserve surface water, which could be utilized during winter. At the beginning of modern irrigation, surface water, which is extracted by LLP, was utilized more than the other methods. Following the subsidized rental system, the expansion of LLPs started from the mid 1970s.

The spurt of expansion of ground water development began in 1967-68. In recent years, the relative importance of ground water has been growing. Total use of tubewells is higher than LLPs. Irrigation by DTWs and STWs has grown in those areas where adequate surface water is not available.

Area irrigated by DTWs slowly increased between 1970-71 and 1976-77 and then rapidly till 1984-85. After this, it increased gradually. In recent years, STW has become the most popular irrigation method due to ease of installation. However, the *Barind* of northern Bangladesh and Chittagong Hill Tracts are unsuitable for STW irrigation.

Area irrigated by different methods in Bangladesh is presented in Table 2.5. From this table it is observed that area irrigated by modern methods has gradually increased over time. During 1972-73 only 38 thousand acres were irrigated by DTWs but in 1994-95 it gradually increased to 1650 thousand acres. In case of STWs, only 4 thousand acres were irrigated in 1972-73 but it rapidly increased to 3812 thousand acres in 1994-95. From this table it is also observed that to irrigate

Table 2.5 : Area Irrigated by Different Methods in Bangladesh, 1972-73 to 1994-95

(in thousand acres)

Year	Methods		
	DTWs	STWs	LLPs
1972-73	38	4	1165
1973-74	61	4	1407
1974-75	118	7	1442
1975-76	154	13	1363
1976-77	161	18	1232
1977-78	408	59	1370
1978-79	504	93	1434
1979-80	582	132	1535
1980-81	641	244	1645
1981-82	799	499	1740
1982-83	963	738	1844
1983-84	1026	750	1647
1984-85	1090	742	1681
1985-86	885	770	1504
1986-87	957	787	1630
1987-88	1068	408	1302
1988-89	1240	510	1625
1989-90	1058	876	1624
1990-91	1520	2795	1667
1991-92	1621	3196	1692
1992-93	1594	3302	1695
1993-94	1586	3536	1651
1994-95	1650	3812	1622

Source : *Statistical yearbook of Bangladesh* (various issues) Dhaka : Bangladesh Bureau of statistics and Khalil, I. (1991), *The Agricultural sector in Bangladesh : A Data Base*, Dhaka : US Agency for International Development.

the cultivated area, STWs played the most dominant role. Area irrigated by LLPs was about 1165 thousand acres in 1972-73 and in 1994-95 it increased to 1622 thousand acres.

Area irrigated by DTWs in Bangladesh is graphically displayed in Figure 2.3.a. From this figure, it can be seen that area irrigated by DTWs increased gradually while fluctuations were observed for some specific years. Figure 2.3.b indicates the area irrigated by STWs in Bangladesh. This figure shows the insignificant performances of STWs in the initial years. But from 1977-78, area irrigated by STWs gradually increased and from 1989-90 it rose sharply till 1994-95. This happened due to removal of duties and standardization of restriction of imported small disel engines which started from 1988-89 (GOB, 1990). Area irrigated by LLPs in Bangladesh is represented in Figure 2.3.c. As compared to DTWs and STWs, a slow increasing tendency of LLPs were found in this figure where quite fluctuations were also observed.

Area irrigated by different crops has also increased over the years. Table 2.6 presents the recent trends of area irrigated by crops for the last five years of the sample period. From this table it is seen that area under different crops of which rice is dominant and it has been gradually increasing over the years. Next to it comes wheat, which occupies more area than other cereals potato, vegetables, oilseeds, sugarcane etc.

Figure 2.3.a: Area Irrigated by Deep Tubewells (DTWs) in Bangladesh, 1972-73 to 1994-95

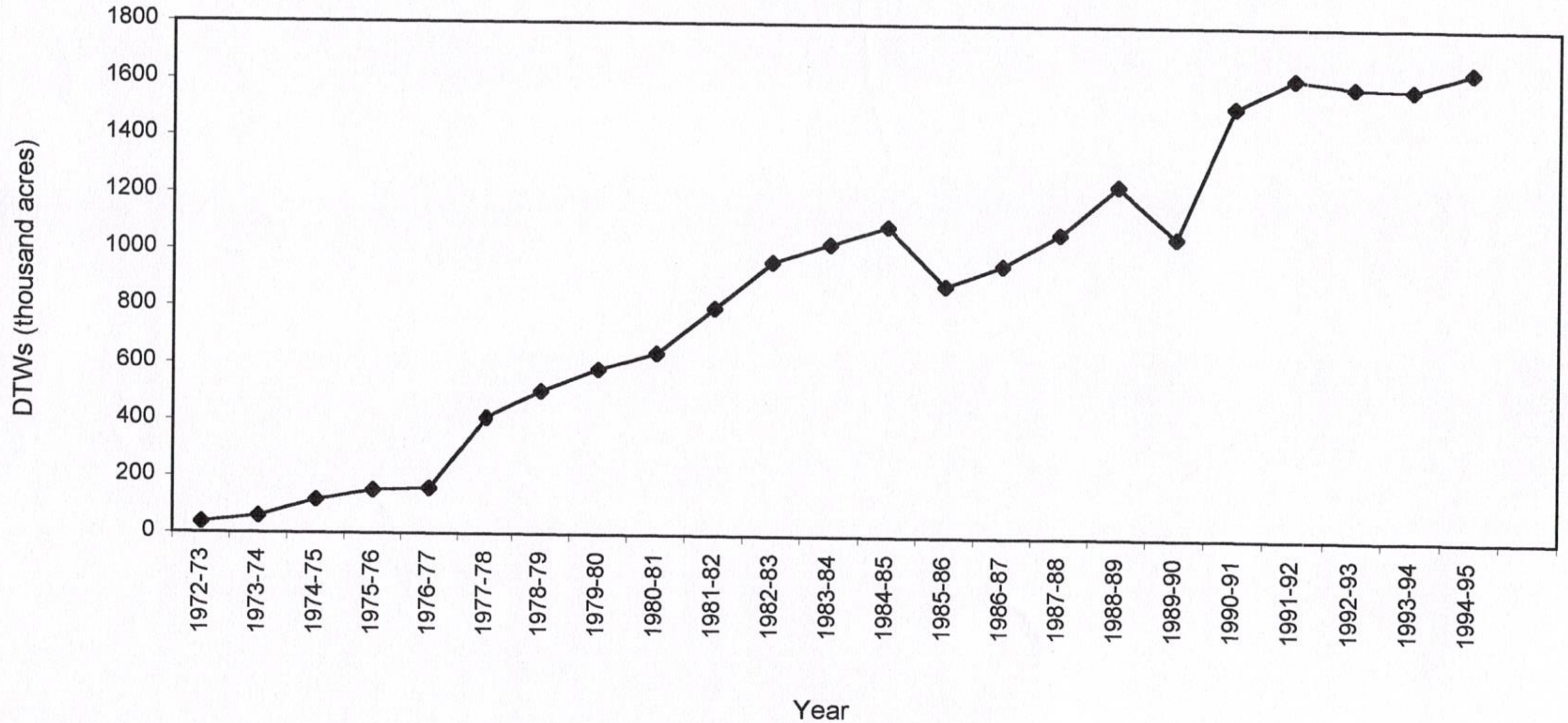


Figure 2.3.b: Area Irrigated by Shallow Tubewells (STWs) in Bangladesh, 1972-73 to 1994-95

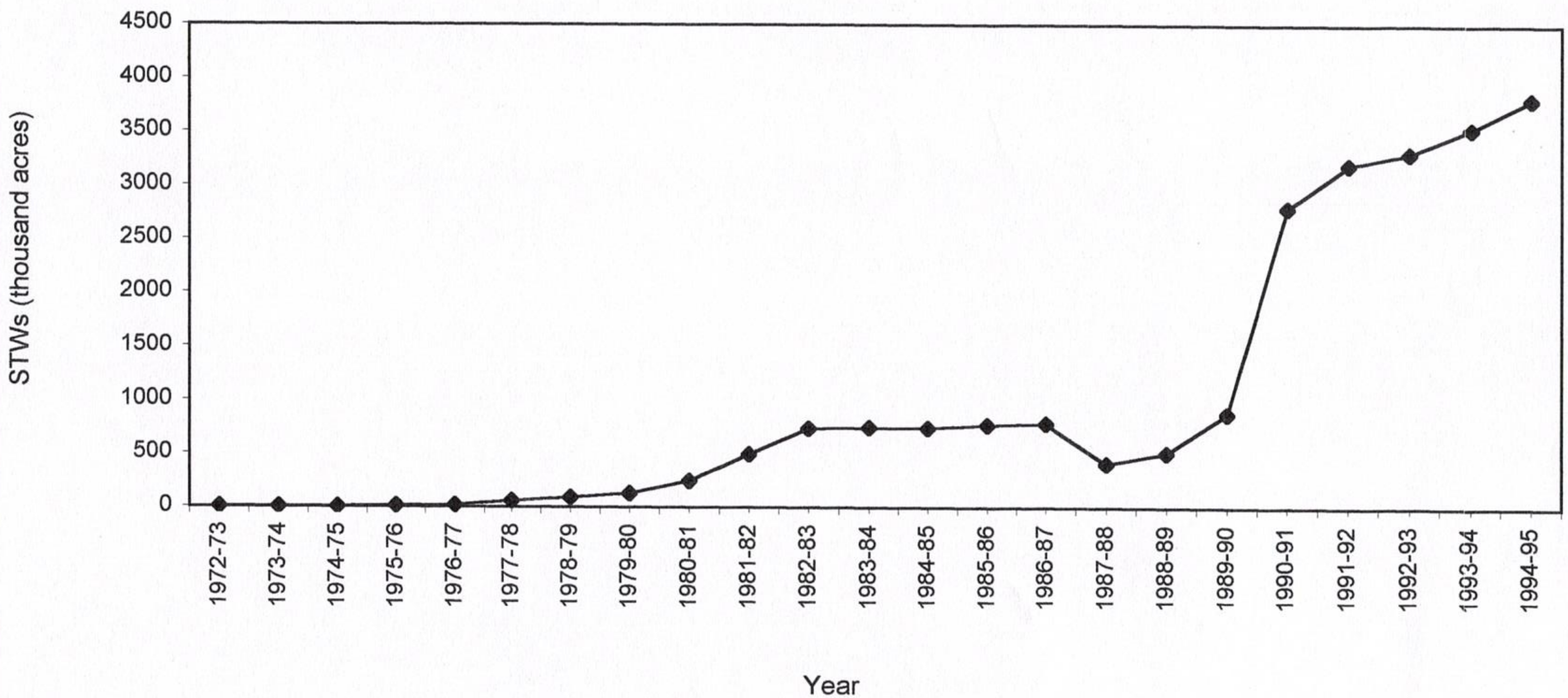


Figure 2.3.c: Area Irrigated by Low Lift Pumps (LLPs) in Bangladesh, 1972-73 to 1994-95

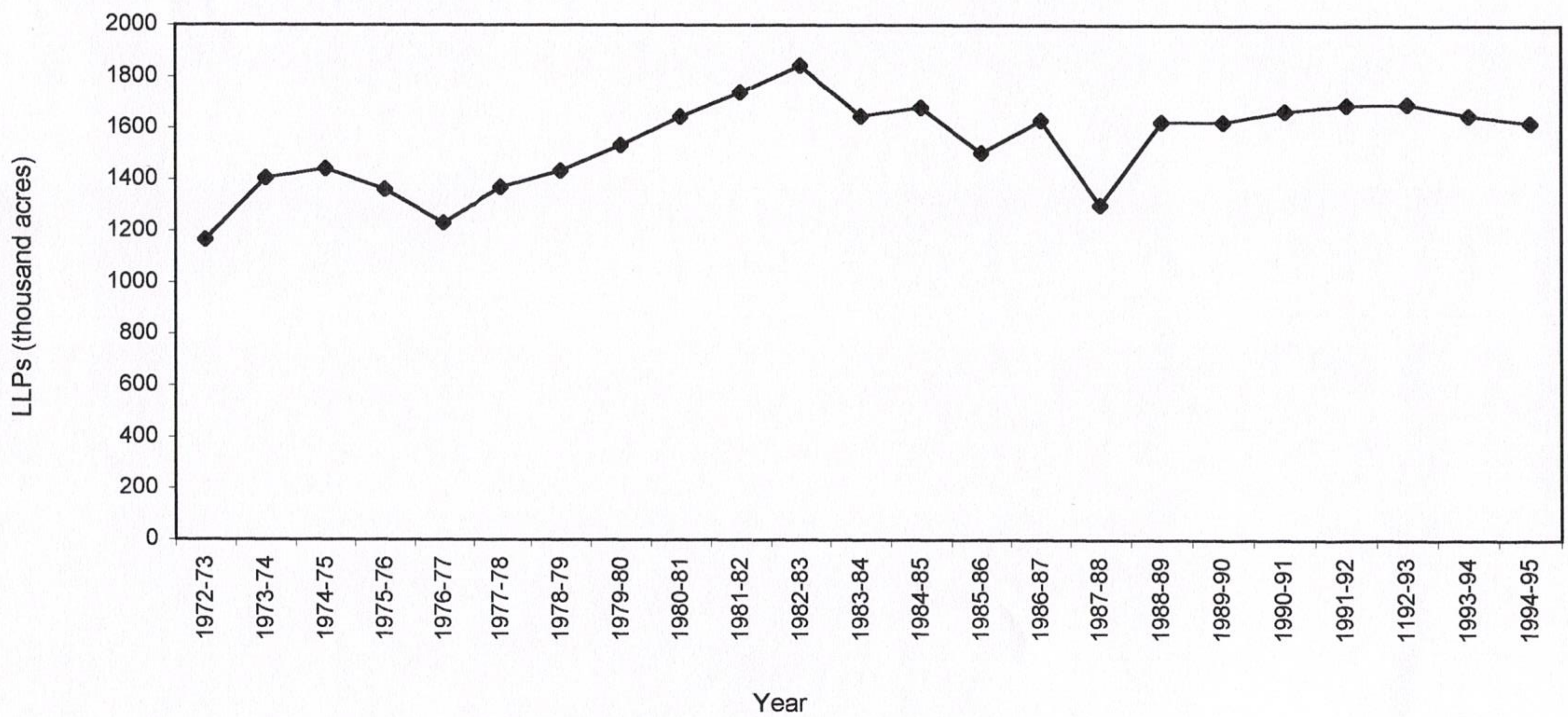


Table 2.6: Area Irrigated by Crops in Bangladesh, 1990-91 to 1994-95

(in thousand acres)

Crops	1990-91	1991-92	1992-93	1993-94	1994-95
Rice	6125	6681	6690	6709	7011
Wheat	698	642	673	672	699
Other Cereals	10	10	10	10	9
Oilseeds	30	31	36	38	44
Potato	202	197	204	218	237
Vegetable	191	190	200	218	220
Sugarcane	25	22	28	31	35
Cotton	12	11	11	17	19
Others	186	194	186	206	188
Total	7479	7978	8038	8126	8472

Source : *Statistical Pocketbook of Bangladesh 1994 and 1997* , Dhaka: Bangladesh Bureau of Statistics.

2.2 Output Growth

Since independence, technological transformation has accelerated with the availability of modern techniques, inputs and equipments. Yet the modernization process is far from complete due mostly to farmer's lack of resource for investment, deficient input delivery, and inadequate infrastructure. Recent performance in the agricultural sector is influenced by two major factors, natural phenomena, e.g. flood, drought, cyclone, etc. and policy changes particularly in case of input distribution and pricing system (GOB, 1990).

On the adoption of new technology and on the pattern of high yielding variety (HYV) cultivation in Bangladesh, two sample surveys were conducted in 1986 and on these points, Hossain (1991:240) arrived at the conclusion, as can be seen in the passage quoted below:

> Our study confirmed that even though the pace of adoption of new technology continues to remain slow, the smaller land holders show greater responsiveness to the cultivation of HYVs. The cost-hike due to the rapid withdrawal of subsidies on inputs and the privatization of input trade along with irregularities in the supply of essential inputs are found to be the principal factors causing declaration in the adoption of new HYV technology in rice cultivation. About 34 percent of the respondents could not cover their costs. Since the cost component becomes higher, the risk in the adoption of new technology becomes greater. This acts as a deterrent particularly to small land holders who happen to be the principal agents of change in Bangladesh agriculture.

Due to adoption of seed–water–fertilizer technology there is a rapid transformation in cereal production. Hossain (1988) looked into this issue, before and after introduction of modern technology. A comparative figure of the growth of crop production can be found from Table 2.7. From Table 2.7 it is observed that after introduction of the modern technology, progress in cereal crops affected the non-cereal crops. During the period 1971-85, the area under cereal crops increased at the rate of 1.16 percent annually while the area under non-cereal crops decreased by 0.73 percent annually in the same period.

Table 2.7: Growth of Cereal and Non-Cereal Crops, Before and After Introduction of Modern Technology in Bangladesh

	Trend rate of growth		
Crops/Period	Cropped Land	Yield per unite land	Production
		(Percent/Year)	
Cereal			
1950-71	1.10	1.52	2.62
1971-85	1.16	2.20	3.36
Non-Cereal			
1950-71	1.26	0.89	2.15
1971-85	-0.73	1.26	0.53

Source: Hossain, M.(1988), *Nature and Impact of the Green revolution in Bangladesh* : Research Report 67, Washington, D.C : International Food Policy Research Institute/Bangladesh Institute of Development Studies, P. 36.

Though the country has tried to achieve self-sufficiency in food grains the average annual growth rate in the agriculture sector declined due to rapid population growth. For the period 1972-73 to 1979-80, the average annual growth rate in the agricultural sector was 3.5 per cent while it declined to about 2.7 per cent over the 1980-81 to 1984-85 period. This picture indicated the poor performance of agriculture sector in the latter period (GOB, 1990). The year 1993-94 and 1994-95 witnessed a decline in food grain production due to natural disasters particularly for floods and droughts. From 1990-91 to 1992-93, the average food grain production was 19.31 million mt but it dropped to 18.71 million mt in 1993-94 and 1994-95 (GOB, 1998).

Adoption of modern inputs like irrigation, fertilizer and insecticides influenced the intensity of cropping. Besides, fixed land and growing population also influence the intensity of cropping. Cropping intensity, which can be expressed as the ratio between total cropped areas and net cropped area (net area sown) and is normally indicated in terms of percentage.

In the early fifties, no significant intensity of cropping was found. But in the sixties, the intensity of cropping increased rapidly. In 1960-61, the intensity of cropping was 130 percent and it increased to 148 in 1969-70. After independence, the intensity of cropping gradually increased over time. Table 2.8 exhibits the trends of intensity of cropping. From this table, it is found that in 1972-73, intensity of cropping was about 145 percent and it gradually increased to over 174 percent in 1994-95. Intensity of cropping in Bangladesh is shown in Figure 2.4, which shows a gradual increasing tendency of intensity of cropping.

In Bangladesh, out of the net cropped area of 7.60 million hectare, about 55 percent is double cropped and approximately 15 percent is triple cropped while about 30 percent is still single cropped (GOB, 1998). Table 2.9 presents the trends of land utilization, which exhibits the statistics of single-cropped area, double-cropped area and triple-cropped area. It is seen from Table 2.9 that in 1974-75 single-cropped area was 12481 thousand acres and it gradually decreased to 7228 thousand acres in 1994-95. While single-cropped area decreased over time, double-cropped area and triple-cropped area have gradually increased.

Table 2.8 : Intensity of Cropping in Bangladesh, 1972-73 to 1994-95

(in percent)

Year	Intensity of Cropping
1972-73	144.95
1973-74	146.25
1974-75	145.51
1975-76	148.48
1976-77	148.89
1977-78	150.73
1978-79	153.10
1979-80	153.18
1980-81	153.70
1981-82	153.86
1982-83	154.66
1983-84	153.16
1984-85	152.18
1985-86	154.47
1986-87	159.44
1987-88	166.19
1988-89	168.19
1989-90	168.42
1990-91	171.70
1991-92	180.81
1992-93	174.35
1993-94	174.52
1994-95	174.64

Source : *Statistical Yearbook of Bangladesh* (Various issues) and *Yearbook of Agricultural Statistics in Bangladesh* (Various issues), Dhaka: Bangladesh Bureau of Statistics.

Figure 2.4: Intensity of Cropping in Bangladesh, 1972-73 to 1994-95

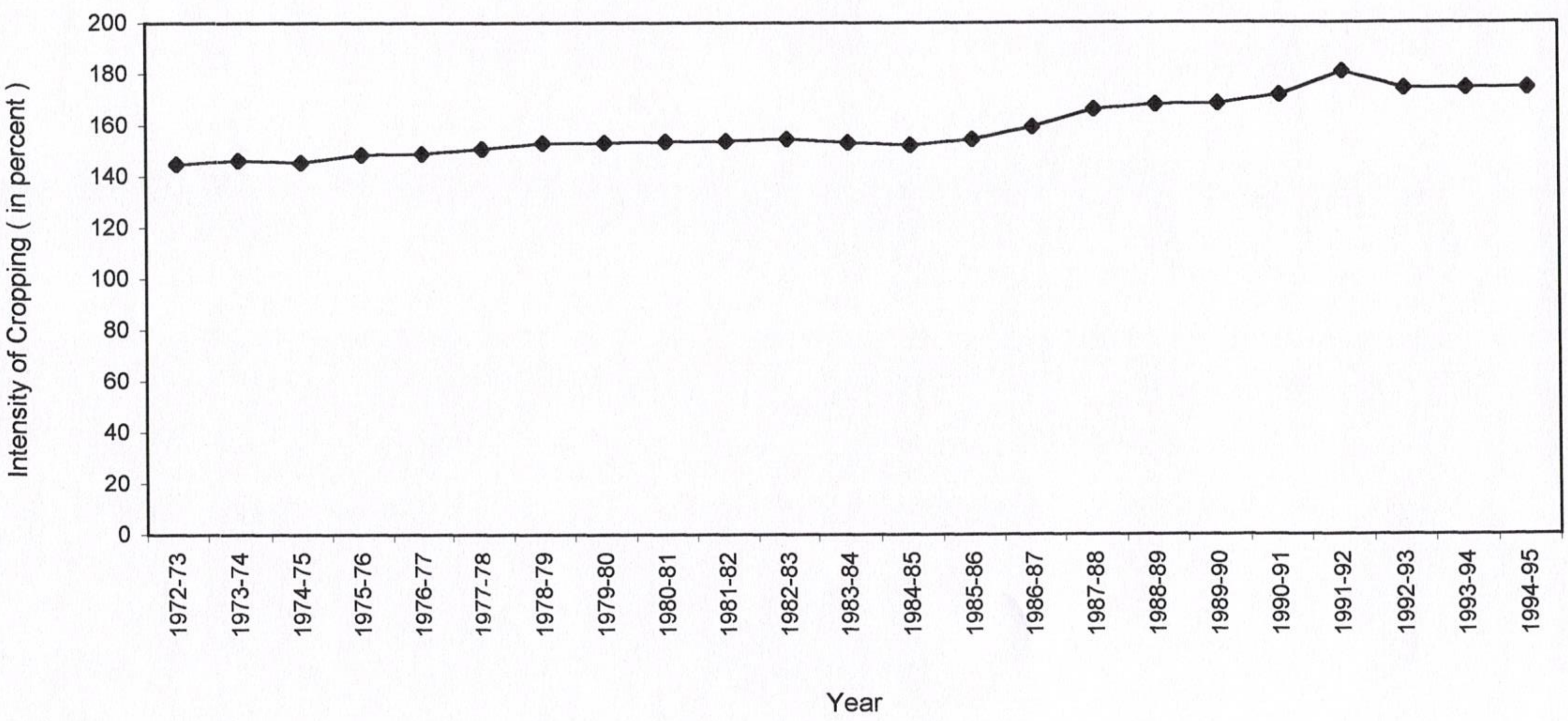


Table 2.9 : Trends of Land Utilization in Bangladesh, 1974-75 to 1994-95

(in thousand acres)

Year	Single-cropped	Double-cropped	Triple-cropped
1974-75	12481	6711	1279
1975-76	12250	7269	1449
1976-77	11911	7072	1462
1977-78	11683	7520	1489
1978-79	11364	7826	1610
1979-80	11390	7865	1618
1980-81	11456	8040	1661
1981-82	11464	8070	1678
1982-83	11336	8251	1689
1983-84	11526	8340	1512
1984-85	11626	8199	1472
1985-86	11516	8492	1653
1986-87	10781	9189	1908
1987-88	9168	8949	2362
1988-89	8825	8908	2415
1989-90	8980	9191	2463
1990-91	8140	9634	2424
1991-92	8387	10722	2652
1992-93	7416	9566	2436
1993-94	7229	9497	2364
1994-95	7228	9530	2375

Source: *Statistical Yearbook of Bangladesh* (Various issues), Dhaka: Bangladesh Bureau of Statistics.

In 1968, modern variety (MV) rice was first introduced in Bangladesh, which needed irrigation facilities and application of fertilizer. In the early seventies, modern variety of wheat was also introduced which was less dependent on irrigation. In increasing the agricultural production both MV *boro* and MV wheat played significant role in Bangladesh Agriculture. In a particular country, cropping pattern largely depends on its nature of land and climate. In Bangladesh, many varieties of crops are produced. These may be classified into groups such as cereals, cash crops, pulses, oilseeds, vegetable, spices etc. Among cereals, rice is most important and it alone accounts for over 95 percent of the total food grains. Next important crop is wheat. Other cereals such as maize, barley, *kaon, cheena, joar bazra*, etc. are also grown in Bangladesh in insignificant quantities.

Form 11.8 million tons in 1976-77, rice production gradually increased to about 17 million tons during 1994-95. Wheat is a fertilizer intensive crop. It needs only 35 percent as much water as rice and requires a much shorter maturing period than *boro* rice growth in the same season. During 1994-95, 890 thousand metric tons wheat was produced in the country.

Cash crops play a significant role in our economy. Among the cash crops, jute is dominant and it is the major fibre crop in the country. Production of raw jute fluctuates greatly and its production was somewhat slow over the last decade, due mostly to the decline of the relative importance of jute. Production of jute was 961 thousand metric tons in 1994-95. Tea is the second important export-crop of Bangladesh next to jute. About 118 thousand acres of land are used for tea plantation and tea production, which has been hampered by floods and droughts. Bangladesh produced about 113 million lbs. of tea in 1994-95.

In case of sugarcane, about 445 thousand acres of land are used for sugarcane production and 7.5 million tons of sugarcane was produced in Bangladesh in 1994-95. Tobacco, a minor cash crop in the country, has achieved self-sufficiency by 1980. Since 1973-74, efforts have been made for the expansion of tobacco cultivation and the country produces about 38 thousand metric tons of tobacco annually.

In Bangladesh pulses[1] are considered major source of protein for the poor. In 1979-80 production of pulses was 214 thousand metric tons, which increased to 534 thousand metric tons in 1994-95.

Among the varieties of oil seeds, rape and mustard generally account for about one-half of total production. Production of rape and mustard remained nearly constant in the late sixties while the output of *til* and groundnut was insignificant. The production of oil seeds was 453 thousand metric tons in 1994-95.

In Bangladesh, wide varieties of winter vegetables such as potato, radish, tomato, cauliflower, cabbage, brinjal and summer vegetables such as arum, brinjal, pumpkin, bitter gourd, etc. are produced. Of these, the production of potato increased substantially and its output was 1.4 million metric tons in 1994-95.

Spices[2] constitute another major cash crop category and cover about 354 thousand acres of land. The yield per acre is very poor due to cultivation of local varieties and use of age old techniques in the cultivation process. The country produced about 318 thousand metric tons of spices in 1994-95. Fruits (mango,

[1] *Masur, moong,* Gram, *Mashkalai, Arhar, Kheshari,* etc.
[2] Turmeric, Ginger, Chillies, Onion, Garlic etc.

banana, jack fruit, coconut etc.) grow in almost all regions of Bangladesh. About 389 thousand acres of land are devoted to fruit cultivation yielding a production of 1.42 million tons annually.

Agricultural performance, particularly crop sector performance, depends on the progressive adoption of modern techniques, inputs and equipment's. Farmers lack of resources for investment, deficient input delivery, inadequate infrastructure, traditional and inefficient practices, etc. are considered as the major hindrances to improved agricultural performance. These, combined with flood and other natural calamities, have somewhat stifled the growth of the agriculture sector.

2.3 Summary

This chapter contains a description of changing input use and crop sector performances in Bangladesh agriculture. Since independence, a significant change in the use of major agricultural inputs was witnessed due to adoption of modern technology like fertilizer and irrigation in the Bangladesh agricultural sector. As a core factor of production, total cropped area increased moderately during 1972-73 to 1994-95. During the sample period, labour force in the agricultural sector has decreased substantially due to the transfer of agriculture labour force to the non-agriculture sector. Consumption of chemical fertilizers increased markedly and as the most modernized component, the use of irrigation also increased during this period.

In increasing the crop production, the MV *boro* and MV wheat played an important role. Among the non-cereal group, potato is important but the production of jute, pulses and oilseeds was not very satisfactory.

CHAPTER 3

LITERATURE SURVEY

This chapter is concerned with a brief survey of earlier flexible from studies. Following the development in production-cost theory, flexible forms have been considered as improved measures of the nature of factor substitution and technical change both in the agricultural and in the non-agricultural sectors. This chapter provides a review of the selected research works, which have been published in various journals. This chapter is divided into two parts. In the first part, a general survey of selected flexible form studies on factor substitution is made. In the second part, previous research works on factor substitution in the agriculture sector are briefly surveyed.

3.1 A General Survey of Selected Flexible Form Studies on Factor Substitution

Christensen, Jorgenson and Lau (1973) advanced a new production function which permits a greater variety of substitution and transformation than the frontiers based on the constant elasticity of substitution function. The authors represented the production function as the transcendental logarithmic production possibility frontier and, in an analogous manner, the price possibility frontier as the transcendental logarithmic price possibility frontier. In the study of production, among many of the production and price frontiers, the translog frontiers can indicate the accuracy of global approximations. The authors tested various restrictions on the parameters of the translog production frontier. Based on the translog production frontier and price frontier, they studied the US private domestic economy for the period of 1929 to 1969. The data on prices and quantities of investment and consumption goods as output and labour and capital services as inputs were used in this empirical study. As in the study of capital-labour substitution, production possibility frontier characterised by additivity and homogeneity was considered useful. For both direct and indirect tests, their empirical results were consistent with a very extensive set of restrictions. Their approach, the transcendental logarithmic production function, was explained by them (1973 : 42) thus:

> We conclude that the assumption of commodity-wise additivity that underlies the constant elasticity of substitution production function is unsuitable as a basis for representing a production possibility frontier with several outputs and several inputs. Group-wise additivity implies that inputs and outputs, considered as commodity groups, must be additive. Multi-level additivity implies that the production possibility frontier is self-dual; the price possibility frontier has the same functional form with parameters that depend on the parameters of the production possibility frontier.

Berndt and Wood (1975) applied the translog cost function in US manufacturing sector for the period 1947 to 1971. He studied factor substitution and demand for energy and used four inputs – capital, labour, energy, and material. They obtained a substitution relationship between energy and labour and a relation of complementarities between energy and capital. In the traditional two-input (capital and labour) studies, they found capital and labour were substitute. They also found that energy demand is responsive to a change in its own price. For the value-added specification Leontief aggregation the US manufacturing data does not satisfy condition and Hicksian aggregation condition. The separability conditions were also not satisfied by the data.

Berndt and Wood (1979) provided analytical and empirical interpretation of energy-capital complementarity consistent with the evidence of energy-capital substitutability. Using time series data of capital, labour, energy, and other non-energy intermediate goods for US manufacturing, the authors found complementarity relationship between energy and capital. Fuss (1977) for Canadian manufacturing, Swain and Friede (1976) for the West German industrial sector also obtained the same result. On the other hand, Griffin and Gregory (1976) and Pindyck (1977) reported substitutability relationship between energy and capital in their study of OECD (Organisation for Co-operation and Development) manufacturing. Berndt and Wood (1979) estimated translog cost share equation using time series data on capital, labour, and energy for US manufacturing. They found that though energy and capital were gross substitutes, they were net complements as well. Berndt and Wood also estimated translog KLEM cost function for Canadian manufacturing based on pooled cross-section and time series data of British Columbia and Ontario provinces. In this study, they also found that energy and capital were gross substitutes but net complements. They proved that the Griffin-Gregory's (1976) estimates were consistent with energy-capital complementarity given by Berndt and Wood (1979). In this study they showed that

Griffin-Gregory's results were not inconsistent with their time series result of energy-capital complementarity.

Stevenson (1980) presented a model based on the translog cost function, which may be useful to test the technological advancement and to test the induced technological bias. In this study, he used firm-level data for a pooled cross-section and time series sample. The data consists of 81 firms for the privately-owned electric utility generating industry for the two years 1964 and 1972. The firms chosen in this study had at least 75 percent of their output from fossil fuel plants. In this study, Stevenson found existence of technological advancement and technological bias including the factor-input and scale biases. These empirical estimates did not support existence of induced technological bias.

Griffin (1981) provided a clarification of gross and net complementarity, which is reported by Berndt and Wood (1979). In this paper, Griffin (1981) tried to have a reconciliation among the original estimates of Berndt-Wood (1979) and Griffin-Gregory (1976). According to Berndt and Wood (1976), in a production sub-function, the energy and capital may be gross substitute whereas in the aggregate production function these two inputs may be net complements. By omitting materials (M) and by using only capital (K), labour (L), and energy (E), energy-capital substitutability can be found and a gross elasticity can be obtained. By considering the KLE aggregate and M, the net elasticity can be obtained which indicates the energy-capital complementarity. In an another study, Griffin (1981) found energy-capital substitutability by considering all four inputs (KLEM) and commented that the difference of gross and net elasticity was unable to give complete explanation of substitutability and complementarity. In another study, Griffin (1977) found energy-capital complementarity in petroleum refining industry and a near zero partial elasticity of substitution was found in the iron and steel industry. In that study, he kept the short-run versus long-run controversy at a distance. Here, Griffin doubted the validity of Berndt-Wood's explanation and by using the Berndt-Wood data and excluding materials he found gross energy-capital complementarity and in this case Berndt-Wood's own data failed to prove their conclusion. Griffin also suggested that in the estimates of long-run capital-energy substitution, a pooled inter-country sample is more appropriate than Berndt-Wood's US aggregate time series approach.

Following the above assessment given by Griffin, in the same year, Berndt and Wood (1981) replied and put forward new evidence in point estimates of capital-energy elasticities. The net and gross elasticity distinction reduce the disparity between the Berndt-Wood and Griffin-Gregory estimates of capital-energy price elasticities. According to Berndt and Wood, Griffin-Gregory's estimates were not statistically different from capital-energy complementarity due to large confidence intervals.

Rushdi (1982) used the translog cost function to study factor substitution in the manufacturing industries of Bangladesh. This study is based on the data of the manufacturing sector over the period of 1969-70 to 1978-79. Using three inputs-- capital, labour, and materials-- he found that the three inputs were complements in production. In this study, the own price elasticity had the appropriate signs where they were all significantly below unity.

Braeutigam, Daughety and Turnquist (1982) estimated a flexible functional form (translog) for a single railroad firm. Their study was based on time series data. The authors tried to incorporate engineering information about technology of the railroad firm. In this study, speed of a shipment was used as a stochastic output for a railroad. The objective of the engineering models was to obtain expected speed. In the estimates of elasticity of substitution, it was found that there was a limited opportunity to substitute between the factors of production of the railroad firm. Substitution relationship was found between labour and equipment. In this study, fuel and labour was found more substitutable than labour and equipment. In calculating the average speed of service, monthly data over nine years on loaded car-miles, prices of inputs, and measure of fixed inputs were combined in this study. This study rejected the joint separability and homotheticity hypotheses.

Merrifield and Haynes (1984) applied the trnslog production function to study factor substitution in the Pacific-Northwest forest products industry. In this study, aggregated lumber and plywood has been considered as output. They used three inputs – labour, stumpage, and capital. To estimate the output demand, data were used for the period 1950-76. Elasticity estimates indicated that less labour and more stumpage and capital would be used in the production due to increased wage. The authors found in their study that substitution possibilities existed between labour and capital, and stumpage and capital. The substitution effect was found stronger than the output effect. The elasticity of price transmission between stumpage and product markets was found to be low due to the substitution possibilities, which occurred in the market process. The elasticity of derived demand for labour was relatively low which indicated that there was a limited impact of wage concessions on the employment in the Pacific-Northwest forest products industry.

Sav (1984) used a broad-class linearly homogeneous CES production function to estimate the substitution possibilities between the capital-intensive solar energy and non-renewable energy sources. This study empirically estimated substitution possibilities between the South-East (SE) and North-East (NE) regions of the United States relating to favourable solar climatic condition. As compared to the NE region, gross substitution elasticities indicated that solar tax incentives more effectively created a substitution of solar for conventionally produced energy in the SE region. Generally, it is expected that substitution possibilities are higher in the more favourable solar climate conditioned SE region than NE region. Following the values of Allen Elasticity of Substitution, it was found that there was a complementary relationship between fuel F and solar-process-capital K in the NE region while there was a slightly larger complementary relationship between F and K in the SE region.

Wohlgenant (1984) used the flexible functional forms to estimate the demand elasticities for food. His econometric estimates were based on three functional forms – Fourier, translog and generalized Leontief. He compared the Fourier flexible forms with the translog and generalized Leontief and concluded that the Fourier flexible form (Gallant, 1981) performed the best. In this study, he used annual data on food and non-food commodity aggregates for the US postwar period (1948-78). He found similar elasticities from translog and generalized

Leontief but different elasticities were found from the Fourier function. The translog and generalized Leontief formulations indicated a slight change in price elasticities over the sample period, but the Fourier form indicated lower price elasticity for the first part of the sample period and thereafter higher price elasticity for food was found.

Considine and Mount (1984) used a linear logit model which is appropriate for incorporating dynamic adjustment. A linear logit model is a flexible functional form which represents a system of cost share equations. In this study, they compare the static and dynamic models. This study is based on a pooled cross section and time series sample from 14 North-Eastern and North-Central states for the period of 1964 to 1977. To estimate demand for electricity, natural gas, oil gasoline and diesel fuel, both static and dynamic models were used. In this study, fuel was considered as energy, which was separable from labour, capital, and material. In this study, all the static own price elasticity estimates were found lower than the long-run estimates. In the static model, electricity and natural gas appeared as complements while they turned out to be substitutes in the dynamic model. In the dynamic model, the short-run price elasticities indicated that there was limited substitution possibilities among fuels. The empirical study indicated that the use of static models of input demand system overstated short-run own price elasticities while it understated the corresponding long-run price elasticities.

Pollack, Sickles and Wales (1984) introduced a new single-product cost function called the CES-translog. Combination of CES and translog, the CES-translog is also a flexible functional form, which is consistent with a wide range of substitution possibilities. They estimated this cost function under a homothetic technology and Hicks-neutral technical progress where factor prices were treated as exogenous. Three types of data were used in this study:

(1) A time series data on capital, labour, energy, and materials of 25 years in US manufacturing sector which was given by Berndt and Wood (1975);

(2) A time series data on coal, energy, natural gas, and electricity of 19 years observation for 5 Dutch manufacturing industries used by Magnus and Woodland (1980); and

(3) A cross-section data on three inputs, capital, labour, and energy for 109 steam electric generating plants from Cowing (1970).

In this study, Pollack *et al.* estimated three types of functions – (a) the CES, (b) the translog and (c) the CES-translog. They found that the CES-translog performed significantly better than the CES in all eight samples. The CES-translog also showed superiority over the translog in all but one. Some inconclusiveness remained, however, which the authors (1984:607) explained thus:

> If our goal were to estimate elasticities at price situations corresponding to the end-point of a time series sample with trended prices, it is not clear that the CES-translog yields better estimates than the CES, nor that the translog yields better estimates than the Cobb-Douglas. Unfortunately we have no more to say about this important issue.

Aw and Roberts (1985) used the translog unit cost function to estimate the import demand and substitution elasticities for US imports from Newly

Industrializing Countries (NICs). To estimate the substitution possibilities a classification of three types of US trading partners are made in this study. The first is ten developed countries, second included the five major Asian NICs, while the third included the South and Latin American NICs. The study is based for the period 1960-1980. US imports from Asian and South American NICs appeared as complements for domestic labour while it was found to be substitutes for domestic capital. US imports from developed countries appeared as substitute for both capital and labour. They also found clear evidence of technical change.

Bairam (1991) first applied the Variable Elasticity of Substitution (VES) production function to the case of Bangladesh. Another form of transcendental production function, the VES is used to study capital-labour substitution. He used cross-section data from 47 sectors of the Bangladesh economy for the year 1977-78. These sectors are divided into three groups, which are (a) low elasticity of substitution, (b) unit elasticity of substitution and (c) high elasticity of substitution. Estimates of elasticity of substitution indicated that elasticity of substitution varied from sector to sector. Elasticity of substitution in the capital-intensive fuel industries were found to be low while the light industry mostly showed unit elasticity of substitution. The empirical results also implied that the overall elasticity of substitution between labour and capital might tend to decline due to any shift from the service sectors to light industry sectors and this situation might have a negative impact on employment in Bangladesh.

Campbell (1993) estimated the translog cost functions for the USA manufacturing sector. The data for capital, labour, energy, materials, and business services were used in this study. He compared the data of Berndt and Wood (1975) with that of Bureau of Labour Statistics of U.S.A. A considerable difference was found between these two data sets. Using the Kalman filter, the translog cost function is estimated for improvement and an error-correction model is used to make the share equation more dynamic. Under the general error correction model, energy and capital were found to be substitutes while labour and energy were found to be complements which is rather unexpected. In this study, the Kalman filter was not found as a significant improvement. For the static and general error correction model, monotonicity, own price elasticity and concavity were all violated.

3.2 A Selective Survey of the Flexible Form Studies in the Agriculture Sector

The first application of flexible form to the agricultural sector was made by Binswanger (1973). He used the translog function to study factor substitution and technical change in the US agriculture. He applied the homothetic cost function using five inputs -- land, labour, machinery, fertilizer, and other inputs. He found both substitutability and complementarity relationship between different inputs. Most estimates of elasticity of substitution rejected the Cobb-Douglas specification. The presence of complementarity also rejected the CES specification. Binswanger found clear evidence of biased technical change in US agriculture.

Brown (1978) studied factor substitution and factor productivity in the US agriculture for the period 1947-60 using both the single- and joint-output versions of the translog function. In the econometric analysis of factor substitution, he used a three-input classification – capital, labour, and materials. Brown found capital-labour and labour-material pairs to be substitutes while capital and material were found to be complements. Brown, like Binswanger, found factor-augmenting technical change in the US agriculture. His estimates of elasticity of substitution were different from unity, which implied rejection of the Cobb-Douglas specification. The presence of complementarity also led to rejection of the CES specification which can not deal with complementarity.

Chotigeat (1978) first applied the translog function to the agriculture sector of a developing country. He used the homothetic translog production function to study factor substitution and input demand in Thai agriculture. Using a three-input model consisting of capital, labour, and fertilizer, he found capital-fertilizer and capital-labour pairs to have substitution relationship while a relationship of complementarity existed in the fertilizer-labour pair. Elasticity of substitution values were obtained which were different from unity. This study did not cover the technical change dimension.

Lopez (1980) studied factor substitution in Canadian agriculture using the generalized Leontief function. He used a four-input classification using inputs of labour, capital, land, and intermediate inputs. In this study, it was found that all four inputs were substitutes. To allow possible scale-effects, he used a non-homothetic cost function. Lopez found that there was no significant evidence of factor-augmenting technical change.

Wyzan (1981) used the translog production functions to the Soviet agricultural sector. By using pooled cross-section and time series data on five crops, he examined various aspects of crop production. Crops included in this study were grain, sugar beet, cotton, potato and vegetables. Wyzan found substitution possibilities between land and labour. His results also showed that output growth for most crops was good.

Islam (1982) first applied the translog function to study factor substitution and technical change in Canadian agriculture. Using the single-output and joint-output versions, both the homothetic and the non-homothetic structures were used to study Canadian agriculture as a whole and for Western Canada separately. He found substitution and complementarity relationship between the factors for both Canada and Western Canada. This study showed inelastic demand for most farm inputs where the own price elasticities of demand were found to be less than unity. The evidence of labour-saving, machinery-using and fertilizer-using biased technical change was found for both Canada and Western Canada.

Boyle (1982) used the translog cost function to estimate the own and cross price demand elasticities for fertilizer in the Republic of Ireland. The principal fertilizer nutrients -- nitrogen, phosphorus, and potassium -- were examined in this study. Capital services, labour services, and other intermediate inputs were considered for deriving elasticity of demand and elasticity of substitution for the period 1958-59 to 1978-79. He found own price elasticity to be greater than one for nitrogen and less than one for phosphorus and potassium. He concluded that the share of nitrogen would likely to increase due to substitution between nitrogen and phosphorus, and nitrogen and potassium.

Chalfant (1984) applied the flexible functional form to study elasticities of substitution in US agriculture. In this study, he tried to generalize the common flexible functional forms and to estimate a demand system for agricultural inputs. The generalized Box-Cox (Berndt and Khaled, 1979) and the logarithmic Fourier flexible form (Gallant, 1981) were mainly used. The translog, the generalized square-root quadratic and generalized Leontief were also included in this study as special cases. Four agricultural inputs -- capital, intermediate input, labour, and land-- were used. In an earlier study, Berndt and Khaled (1979) applied the generalized Box-Cox to the US manufacturing sector. They used data on capital, labour, energy, and materials. Energy-capital complementarity was found in their study. Gallant (1982) compared the logarithmic Fourier flexible form with the generalized Box-Cox and this study did not indicate any energy-capital complementarity. Remembering these past experiences, Chalfant (1984) tried to review these studies on flexible functional forms and found a reasonable result for elasticities by the generalized Box-Cox. The results of this study was different from the earlier studies in agricultural production which were based on the translog and the generalized Leontief functions. In the case of the generalized Leontief and generalized square-root quadratic function, different types of cross elasticities were found between these forms and the elasticity of substitution between capital and labour also varied in this estimation.

Thirtle (1985) applied the flexible functional form (the Two-Stage CES function) to investigate factor substitution and technical change in the agricultural sector for a developed country. US wheat production was chosen from ten US farm production regions. This study was based on the time series data over the period 1939-78. Four inputs -- land, labour, fertilizer, and machinery -- were used. The increase in fertilizer was found to be due to factor substitution but the increase in machinery and the decrease in labour were found to be due to technical change. The empirical results implied considerable increase in the land-labour ratios which was found in US wheat production and it was ascribable to biased technical change rather than factor substitution. In recent years, the controversy between technical change and factor substitution appeared in the US agricultural studies. In this study, Thirtle indicated the importance of technical change and suggested that the major proportion of the changes in the factor ratios can be explained by biased technical changes.

Akridge and Hertel (1986) used the translog cost function to explain the relationship between cost and output for the retail fertilizer plants. In estimating a multi-products translog cost function the inputs -- labour, energy, other variable inputs, and fixed inputs -- were used. Management, plant and equipments were considered as a set of fixed inputs, while fertilizer, chemicals and other farm supplies represented a set of outputs. For estimation, pooled data from 24 Indiana and Illinois retail fertilizer plants for the period 1975-82 were used. In this study it was found that by increasing and diversifying the output, the fertilizer plants could lower average cost. This study also indicated that the multi-product firms had over-invested in plant and equipments.

Kuroda (1987) estimated a non-homothetic translog cost function for the Japanese agriculture sector. This study was based on farm-level data for the period 1952-82. To estimate the translog cost function, five inputs -- labour, machinery, intermediate inputs, land, and other inputs --were used in this study. A composition of fertilizer, agro-chemicals and feed were considered as intermediate inputs. Intermediate inputs, land and other inputs were found to be substitutes for labour. Intermediate inputs appeared as complement for both machinery and land. Combination of biased technical change and non-homotheticity indicated price-induced factor substitution which tended to transfer agricultural labour to the non-agricultural sector.

In another study, Ali (1991) applied the translog function to study factor substitution in UK agriculture. He used both homothetic and non-homothetic versions and incorporated dynamic factor demand analysis. He used a five-input classification -- land, labour, machinery, fertilizer, and energy-- covering the period from 1967 to 1987. In this study, he found both substitutability and complementarity relationship between the inputs. All own price elasticities of demand were found negative. Land-labour, land-fertilizer, labour-machinery and fertilizer-energy were found to be Allen substitutes while machinery and energy emerged as complements. Using both static and dynamic aggregate output models, the study indicated a very high degree of substitutability between fertilizer and energy and substantial degree of complementarity between machinery and energy.

Evidence of machinery-saving and fertilizer-using technical changes was found in UK agriculture during the sample period.

3.3 Summary

It is observed from the above discussion that in the analysis of factor substitution the concept of flexible form has attracted considerable attention in recent years. Due to the restrictive nature of the more frequently used techniques, that is, the Cobb-Douglas production function (C-D) approach and the constant elasticity of substitution (CES or ACMS) approach, all the above studies opted for the flexible forms. In case of the agricultural sector, it is also observed that most of these studies preferred the flexible form and, of these forms, the translog approach has been most widely used.

CHAPTER 4

THE THEORETICAL MODEL

The objective of this chapter is to describe the theoretical model which will be used to study factor substitution in Bangladesh agriculture. Production relations are usually studied using a production function approach where output is regarded as a function of inputs with certain restrictions. Following the developments in production and cost theory, in recent years the flexible functional forms are being widely used to study the production relations. Under the flexible forms, a cost function approach is used which do not impose any *a priori* restriction on the value of the elasticities of substitution. In this study the flexible functional form is used to examine the possible substitution between inputs.

This chapter is divided into five parts. In the first part, the rationale for employing the flexible form is explained. In the second part, the basic translog cost function model is presented. In the third part, the concepts of elasticity of substitution and demand are explained and in the fourth part input classification is outlined. In the fifth part, the estimation methods are discussed.

4.1 Rationale for Employing the Flexible Form

In the empirical study of factor substitution, the production function approach is widely used. The production function approach is of two types, one is *a priori* fixed and other is the flexible form. Among the *a priori* fixed group, Harrod-Domar, Leontief, Cobb-Douglas(CD) and the Constant Elasticity of Substitution

(CES) are dominant. *A priori* fixed production functions are highly restrictive while the flexible forms are not bounded by any *a priori* restrictions. These functional forms are considered as the extension of the *a priori* fixed forms. In the family of production functions, the values of the elasticity of substitution are zero in the Leontief function. For Cobb-Douglas production function it is unity. A later development constitutes the CES function suggested by Solow, Minhas, Arrow, and Chenery (1961). The basic property of the CES production function is to allow the value of elasticity of substitution to assume any value between zero to (plus) infinity. A large number of studies were conducted by using the CES production function. Hence, the CES production function can be used to derive the values of elasticity of substitution other than unity.

The CES function has, however, two important limitations. First, the CES production function is unable to examine complementarity relationship among the pairs of inputs. But complementarity relationship appears quite frequently in agricultural production. Second, it is highly restrictive and it cannot deal with more than two inputs, implying that it is unable to analyze multi-input relationship. In contrast, the flexible forms can consider a large number of inputs and allow any value of elasticity of substitution between two inputs. Thus the flexible forms are able to analyze both the substitutability and complementarity relationships between inputs.

Development of flexible forms started during the 1970s. There are various types of flexible functional forms such as the generalized Leontief, the generalized Cobb-Douglas and the translog cost function. The transcendental logarithmic (translog) function was advanced by Christensen, Jorgenson and Lau (1971). Around approximately the same time, the generalied Leontief (Diewert, 1971) and the generalized Cobb-Douglas (Diewert, 1973) functions were proposed. In 1974, Lau (1974) suggested another type of flexible form – the Quadratic function. Four years later, McFadden (1978) introduced the generalized Concave function. These flexible forms can indicate a second order local approximation to any twice-differentiable production and cost function. In 1981, Gallant (1981) advanced the Fourier flexible form for estimating demand elasticities. This method is also able to globally approximate the price and income elasticities.

Pollack, Sickles and Wales (1984) proposed a new production function, called the CES-translog. It is also a flexible functional form indicating a combination of the CES and the translog cost function. Thirtle (1985) suggested the functional form named the two-stage CES. In 1991, another form of transcendental production function – the Variable Elasticity of Substitution or VES production function-- was proposed by Bairam (1991).

In connection with the use of the flexible forms Berndt and Wood (1975:260) clarified this aspect thus:

> We choose to specify a highly general functional from, one that places no *a priori* restrictions on the Allen partial elasticities of substitution and one that can be interpreted as a second order approximation to an arbitrary twice-differentiable cost function. A variety of functional forms satisfy these requirements – the generalized Leontief, generalized Cobb-Douglas, and translog cost functions all

are sufficiently flexible. We arbitrarily choose to employ the translog cost function.

In case of applications, economists provided divergent evidence on various flexible forms. On the basis of a Bayesian testing technique, Berndt, Dorrough and Diewert (1977) proposed that the translog function performed better relative to the generalized Leontief and generalized Cobb-Douglas functions. In comparing the translog and generalized Leontief functions, Kiefer (1975) concluded that the translog performed well when used with a Box-Cox (Box and Cox, 1964) transformation. Appelbaum (1979), using parametric testing procedures, indicated that the generalized Leontief and the square-rooted Quadratic function to be preferable to the translog function. As compared to the translog, Pollack *et al.* (1984:607) explained their use of CES-tanslog cost function thus:

> According to the likelihood ratio test, it dominates the translog in seven of the eight samples, it satisfies regularity conditions about as often, and it implies substantially different estimates of substitution elasticities. It is possible that these results are an artifact of our data sets or our standard modeling scenario–homothetic technology, Hicks–neutral technical progress, exogenous factor prices, instantaneous adjustment and additive normal, independent disturbances. If our results hold for other data sets and other modeling scenarios, the translog should be replaced as a standard flexible functional form for cost function estimation by the CES-translog.

Shahbuddin (1985) tested the validity of the restrictions imposed by the Cobb-Douglas functional form against the translog production function. About his results, Shahabuddin (1985:97) said:

> To conclude, although the Cobb-Douglas restrictions are mostly validated in our sample, we cannot possibly recommend its 'indiscriminate' use in the estimation of disaggregated production functions in peasant farming because it may not capture the underlying technology of production in some important crop seasons. And to that extent, the use of Cobb-Douglas estimates may introduce considerable bias in such studies analyzing productive efficiency and/ or resource allocation behavior in a peasant agriculture.

Another functional form, the Two-stage CES was suggested by Thirtle (1985). This function is considered less general than the flexible functional forms. Bairam (1991) suggested that VES production function is the appropriate production function to study the elasticity of substitution for the Bangladesh economy.

From the above assessment it can be inferred that the problem of choosing a specific function from various flexible forms is an issue which is difficult to resolve. In recent years, a large number of studies have been done on the agriculture sector. Most of these studies were based on the translog function where a study of the substitution possibilities between inputs was made. Following Binswanger (1973), Brown (1978), and Chotigeat (1978) and several other studies were done by Islam (1982), Boyle (1982), Akridge and Hertel (1986), and Kuroda (1987) all of which applied the translog function in the agriculture sector. Later, Ali (1991) applied the translog cost function to the UK agriculture. Thus, in order to derive a meaningful result and at the same time to retain comparability with most similar studies the translog functional form has been chosen for our study.

Normally, a production function approach is required to examine the production relationship. In spite of certain limitations, the production function approach has been used in several research works. In the production function approach, if high levels of multicollinearity exists between inputs, imprecise estimation may result. This problem can be solved using a cost function approach. Though our study deals with production structure, a cost function approach is used. There are two reasons for using the cost function. Firstly, it is easier to obtain data on prices of inputs. Secondly, cost function can be viewed as a dual of production function under certain conditions (Shephard, 1953). Recently there has been an emergence of interest in using the price based translog cost function approach instead of quantity based production function approach.

In the study for postwar Japanese agriculture, Kuroda (1987:328) illustrated this aspect by saying:

> The cost function is used for three reasons. First, the governments regulation of output prices through price programs during the period under question may have disturbed the principle of marginal cost pricing by farmers. In turn, this implies that the profit function approach may not be appropriate. Moreover, in the late 1970s the Japanese government introduced an allotment program for rice production in order to balance supply with demand. The level of output could then be treated as exogenous. Second, the cost function approach yields direct estimates of the various Allen partial elasticities of substitution. Third, the cost function approach allows us to exploit duality theory without imposing any restrictions on the returns to scale in the underlying technology.

Besides this, about the advantages of translog cost function, Campbell (1993:5) said:

> Typically the price based translog cost function is estimated instead of the quantity based production function for several reasons. At a highly aggregate level quantities of inputs may be exogenous but at a more disaggregate level prices are more likely to be exogenous. Individual firms choose the quantities of factor inputs to use from their prices. When a production function is estimated, quantities of the factor inputs are exogenous and quantity of output is endogenous. When the cost function is estimated, prices of the various inputs are exogenous and quantities used to compute shares are endogenous. Data on prices are more likely to be available than data on quantities. Economists are usually interest in price effects instead of engineering related quantity effects so for economic purposes it is easer and more direct to use cost functions.

It is no wonder, therefore, that among the recent research works, an overwhelming majority has chosen the cost function approach of which about 80 percent are based on the translog cost function.

4.2 The Basic Translog Cost Function

Let us introduce a production function setting the output (Y) as a function of quantities Q_1, Q_2,............,Q_Z . In a usual form, this production function can be presented as

$$Y = Y(Q_1, Q_2, \ldots\ldots, Q_z) \tag{4.1}$$

Here equation (4.1) is considered as twice-differentiable and it is assumed that the changes in the input quantities depend on the changes of output. Hence, by Shephard's Lemma, which indicates that the first derivative of a cost function with respect to the price of input is equal the demand for that input, a cost function exists, reflecting the production technology. Now corresponding to (4.1) the cost function can be written as

$$C = C(P_1, P_2, \ldots\ldots\ldots, P_z, Y) \tag{4.2}$$

where C= total cost and P_1, P_2,.......,P_z are input prices.

Now to empirically estimate equation (4.2), a specific functional form is required. The translog function introduced by Christensen, Jorgenson and Lau (1973) is used in this study. Like other Flexible forms, the translog function does not impose any *a priori* restriction on the values of elasticity of substitution.

In the usual form, the translog cost function can be written as

$$\ln C = a_0 + a_Y \ln Y + \frac{1}{2}\gamma_{YY}(\ln Y)^2 + \sum_i a_i \ln P_i$$

$$+ \frac{1}{2}\sum_i \sum_j \gamma_{ij} \ln P_i \ln P_j + \sum b_{Yi} \ln Y \ln P_i \tag{4.3}$$

where C = total cost

Y = aggregate output

P = prices of inputs.

The possibilities of augmented technical change have not been included in equation (4.3). Incorporating the technical change by including time (t), equation (4.3) can be modified as

$$\ln C = a_0 + a_Y \ln Y + \frac{1}{2}\gamma_{YY}(\ln Y)^2 + \sum_i a_i \ln P_i$$

$$+\frac{1}{2}\sum_{i}\sum_{j}\gamma_{ij}\ln P_i \ln P_j + \sum_{i} b_{Yi} \ln Y \ln P_i$$

$$+\varphi_t t + \frac{1}{2}\varphi_{tt} t^2 + \varphi_t Y^t \ln Y + \sum_{i} \varphi_t P_i\, t \ln P_i \qquad (4.4)$$

Equation (4.4) considers technical change at a constant rate and it can indicate existence and direction of technical change.

The Cost-Share Equations

According to Shephard (1953), the share of an input in total cost can be viewed as its share in the total product. This is called Shephard's Lemma. Following the Shephard's Lemma, the cost-minimizing share equations for the various inputs can be obtained by logarithmically differentiating equation (4.4) with respect to input prices. Now the derived demand equations and the cost-share equations can be presented as

$$\frac{\delta \ln C}{\delta \ln P_i} = S_i = a_i + \sum_{j}^{n} \gamma_{ij} \ln P_j + b_{Yi} \ln Y + \varphi_t P_i t \qquad (4.5)$$

where S_i = Share of the i-th input in total cost.

In this study, the cost-share equations are used for estimation but the cost function is not directly used for estimation. The cost-share equations are estimated with the following restrictions imposed:

(1) Adding up criteria implying that sum of the cost-shares must equal unity. Symbolically,

$$\sum_i a_i = 1$$

$$\sum_i \gamma_{ij} = 0$$

$$\sum_i b_{Yi} = 0$$

$$\sum_i \varphi_{t} P_i = 0 \tag{4.6}$$

(2) Zero degree homogeneity in prices implying that proportional changes in all input prices leave the factor shares unaltered. Symbolically,

$$\sum_j \gamma_{ij} = 0 \tag{4.7}$$

(3) Symmetry implying that typical properties of neoclassical production theory are satisfied:

$$\gamma_{ij} = \gamma_{ji} \tag{4.8}$$

Considering the above-stated restrictions which are placed on equation (4.5), different production structures can be reflected. In this study, both the homothetic and the non-homothetic structure will be empirically estimated. Three modifications of production structures are used in this study. These are :

(1) a homothetic structure without technical change ;

(2) a non-homothetic structure without technical change ;

(3) a non-homothetic structure with technical change ;

4.3 Elasticities of Substitution and Demand

Both the concepts of elasticities of substitution and demand are very important for our study. Normally elasticity of substitution appears in that case, when one factor is substituted for another in response to the changes in their respective prices. It can also be expressed as the ratio of the percentage change in the ratio of the inputs to the percentage change in the marginal rate of substitution between them. From the cost-shares equations both the estimates of elasticity of substitution and elasticity of demand can be derived. In the cost shares equations, the estimated gamma coefficients do not have any clear economic meaning but these form the basis for deriving the estimate of elasticities of substitution and demand. Both in the Allen partial elasticity of substitution (AES) and in the price elasticities of factor demand, the translated forms of gamma coefficients are included. Uzawa (1962) has demonstrated that the AES between two inputs i and j can be expressed as

$$\sigma_{ij} = \frac{C_i C_{ij}}{C_i C_j} \qquad (4.9)$$

where $C_i = \delta C / \delta P_i$

and $C_{ij} = \delta^2 C / (\delta P_i \delta P_j)$

where σ_{ij} denotes AES between inputs i and j. It is seen from the definition that the elasticities of substitution between any two inputs are symmetric. Equation (4.9) has been given in general terms. Now for the translog cost function, the AES is given by

$$\sigma_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j} \qquad (4.10)$$

The own price elasticity is given by the following equation

$$\sigma_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2} \qquad (4.11)$$

where S_i and S_j are the shares of the i-th and j-th input.

It should be noted that in case of the CES function the values of AES are assumed to be constant. But in this study, the values of AES for different sub-periods can be estimated with changes in the values of cost shares.

An integrated study of factor substitution and factor demand necessitates the closely related concepts of elasticities of substitution and price elasticities of input demand. From the estimated gamma coefficients, the price elasticities of input demand (ED) with respect to own and other prices can also be obtained. Allen (1938) states the relationship of elasticity of substitution and elasticity of input demand thus

$$ED_{ij} = S_j \sigma_{ij} \qquad i \neq j \qquad (4.12)$$

$$ED_{ii} = S_i \sigma_{ii} \qquad (4.13)$$

EDs denote the elasticities of input demand where it is assumed that the cross price elasticities are not equal, that is, the share of i-th input may not be equal to the share of the j-th input.

4.4 Input Classification

Early input classifications in production studies were mostly restricted to only two inputs as it is found in the Cobb-Douglas and the CES functions. But after the introduction of flexible forms inclusion of any number of inputs became possible and consequently, other inputs, such as material and intermediate inputs, began to be considered in production function studies.

In this study, corresponding to the translog cost function, the particular cost-share equation of each input is estimated using an input classification consisting of land, labour, fertilizer, and irrigation. Theoretically, the flexible forms can include any number of inputs but practically it is circumscribed by the possible appearance of the problems of multicollinearity. In this study, the input classification is designed to study both durable and non-durable inputs. Our input classification consists of four inputs – land, labour, fertilizer, and irrigation – denoted by N, L, F, and I respectively. Following equations (4.1) and (4.2) and based on these four inputs, the production function can be written as

$$Y = Y\,(Q_N, Q_L, Q_F, Q_I) \qquad (4.14)$$

and the corresponding cost function can be stated as

$$C = C\,(P_N, P_L, P_F, P_I, Y) \qquad (4.15)$$

In a time series study, it is very crucial to have a proper classification of inputs, especially for a less developed country like Bangladesh. Input classifications used in our and other studies are presented in Table 4.1.

Table 4.1 : Input Classification Used in Selected Flexible Form Studies of the Agriculture Sector

Author	Year	Country	Inputs
Binswanger	1973	USA	Land Labour Fertilizer Machinery Other inputs
Brown	1978	USA	Capital Labour Materials
Chotigeat	1978	Thailand	Capital Labour Fertilizer
Lopez	1980	Canada	Land Labour Capital Intermediate inputs
Islam	1982	Canada	Land Labour Machinery Fertilizer Energy
Boyle	1982	Ireland	Fertilizer capital services Labour services Other intermediate inputs
Chalfant	1984	USA	Capital Intermediate inputs Labour Land
Thirtle	1985	USA	Land Labour Fertilizer Machinery
Akridge and Hertel	1986	USA	Labour Energy Other variable inputs Fixed inputs
Kuroda	1987	Japan	Land Labour Machinery Intermediate inputs Other inputs
Ali	1991	UK	Land Labour Machinery Fertilizer Energy
Our Study	2001	Bangladesh	Land Labour Fertilizer Irrigation

From Table 4.1, it is observed that Binswanger (1973), Lopez (1980), Islam (1982), Chalfant (1984), Thirtle (1985), Kuroda (1987) and Ali (1991) used land as an input. It is also observed that everyone included labour as an input. In case of fertilizer, it can be seen that Binswanger (1973), Chotigeat (1978), Islam (1982), Boyle (1982), Thirtle (1985), and Ali (1991), all have used fertilizer as a separate input. Thus, nearly all studies used land and labour as inputs. Coming to the intermediate inputs, we find the inclusion of fertilizer and energy in some studies.

If we consider at Bangladesh agriculture, we find that land and labour should be included as inputs. But for material inputs, irrigation should be included along with fertilizer. Inclusion of energy as a separate input is not warranted because in Bangladesh there has not been any significant use of energy in the cultivation process. Energy use has been mostly done for irrigation, which has been included an input. Thus four inputs – land, labour, fertilizer, and irrigation – have been used in this study to analyze factor substitution.

4.5 Estimation Method

The ordinary least squares (OLS) method is widely used as a technique of estimation due to its ease of computation. But the OLS method is appropriate only for single equation and becomes inadequate when the models using a simultaneous equation framework are to be dealt with. Of the techniques available for tackling the simultaneous equation models, three are dominant. These are the SUR (Seemingly Unrelated Regression), the 3SLS (three-Stage Least Squares) and the FIML (Full Information Maximum Likelihood).

Normally, in a two variable model, the demand for an input is a function of the price of that input while in a multi input model, the demand for an input is connected with the changes in relative prices of other inputs. In this context, a change in the price of one input may effect the use of one or more other inputs depending on the prices of those inputs. In such a situation, the cost-share equations should be estimated simultaneously. The basic mechanism of a simultaneous models is to find the values of one set of the endogenous variables corresponding to the another set of predetermined variables. If the OLS method is used, the estimated derived demand equations can be unbiased leading to inefficiency (Kmenta, 1971). If the explanatory variables can be treated as exogenous, Zellner's (1962) seemingly unrelated regression or SUR can be used in that context.

Some early users of the translog functional form, Berndt and Wood (1975) chose the iterative 3SLS method as the estimation procedure. Four years later, Berndt and Wood (1979) used the full information maximum likelihood procedure.

Other users of the translog specification, Stevenson (1980), Merrifield and Haynes (1984), Pollack *et al.* (1984) and Ali (1991) applied the FIML method as a estimation procedure for their studies. About the advantages of FIML method, Intriligator (1978:412) made the following comments:

> A major advantage of FIML over 3SLS, however, is that with this technique it is possible to use in the estimation process a wide range of a priori information, pertaining not only to each equation individually but also to several equations simultaneously, such as constraints involving coefficients of different structural equations and certain restrictions on the error structure.

In this study, the Full Information Maximum Likelihood (FIML) method has been applied to estimate the cost share equations. Since the sum of cost shares equal to one, the problem may arise where the estimated variance-covariance matrix across equation is singular. To overcome this problem, one share equation has been deleted and an iterative method is used until it converges to an identity matrix to ensure that the estimates are invariant to the share equation deleted. Estimations have been done using the well-known econometric package SHAZAM.

4.6 Summary

In this chapter the rationale for choosing the flexible form is explained and the development of the flexible forms is reviewed. From the selected review of earlier studies, it is observed that the flexible form has played an important role in agricultural studies. The basic translog cost function is presented here. Proper classifications of inputs were reviewed and a comparison of our classification with some selected studies made. For estimating the cost share equations, the Full Information Maximum Likelihood (FIML) method was chosen for this study.

CHAPTER 5

THE DATA

The objective of this chapter is to describe the data, which have been used for estimating the parameters of the translog model. Most of the available data are either incomplete or are not readily available. Therefore, it is necessary to separately construct the input cost shares, price indexes of four inputs and indexes of all output for estimating the coefficients of the cost share equations corresponding to the translog function. This chapter is divided into four parts. In the first part, the data are classified and defined and the second part contains a description of various indexing approaches. The third part of this chapter presents the resulting indexes and cost shares of four inputs for Bangladesh agriculture sector and the last part provides the Divisia indexes of farm output.

5.1 The Cost and Output Data

Farm inputs can be divided into two groups – labour, and non-labour inputs – where the non-labour inputs can again be divided into durable and non-durable inputs. The basic property of the non-durable inputs is that it can be used only once while, in contrast, the durable inputs are used recurringly. The non-durable inputs can also be called intermediate, material or purchased inputs and this group includes fertilizer, direct energy inputs, seeds and feeds.

In case of durable inputs, both opportunity cost and depreciation costs can be allowed. Durable inputs are considered as a stock which generates a flow of services over time. Naturally, it is assumed that there is no depreciation of land while both depreciation and opportunity cost are considered for machinery. The return, which is forgone by investing in durable inputs, is known as opportunity cost. When the durable inputs are used during a period of time they wear out – this can be viewed as depreciation. In this study, both the sum of actual and imputed operating expenses are considered to measure total cost. Estimates of total cost and particular cost shares for inputs are made. Time series data on price and quantities of output and inputs are used in this study. These data on prices and quantities of four inputs are developed for Bangladesh agriculture sector. The data are mainly collected from the official statistical sources of Bangladesh such as the Bangladesh Bureau of Statistics (BBS). The data cover the period 1972-73 to 1994-95. Since this study uses annual data, total number of observations is 23.

Cost of Land

The quantity of land is defined as the total cropped area. The price of land is expressed in taka per acre and it is calculated from unweighted annual rural land price indices (BBS, *Statistical Yearbook of Bangladesh*, various issues). Total cropped area consists of the sum of the net-cropped area and the area sown more than once.

To obtain the cost of land, the sum of opportunity cost of land and real estate taxes are included. In this study, the opportunity cost of land is assumed to be 5 percent. In calculating the opportunity cost over the entire period, the choice of 5 percent is considered as the fixed rate of interest. Such a rate was used by early researchers such as Binswanger (1973) and Islam (1982). Generally, it is assumed that any purchase of land requires some investment of money which would earn some profit if invested elsewhere. On the other hand, one needs money for rent. Thus the opportunity cost of land and real estate taxes are imputed on land. In this study, the year 1972-73 is the base period. To obtain the cost of land, the sum of opportunity cost of land and real estate taxes are included. The cost of land is estimated by multiplying the price of land by quantity of land. The relevant data are obtained from various issues of the *Statistical Yearbook of Bangladesh* published by the Bangladesh Bureau of Statistics (BBS).

Cost of Labour

There are two measurements of labour. These are persons employed, and man-hours. Though the latter is considered to be the better index of quantity of labour (Brown, 1978), it is not available for Bangladesh agriculture sector. Here the quantity of labour is defined as persons employed in agriculture, forestry and fishing. These are available from the reports of various censuses and labour force surveys and are used in this study. Labour force data are available only for the discrete years in which Census and Labour Force Survey have been conducted. Hence, to construct the required annual time series data for the intervening years data have been derived by interpolation. The Bangladesh Bureau of Statistics (BBS) reports the daily wages of agricultural labour with food and without food. This study uses the latter definition and the data are transformed into yearly wages assuming 300 working days per year. This is done to take into consideration idle days which is common in agricultural production. Thus, to obtain the cost of labour, persons employed in agriculture sector are multiplied by yearly wages. Data sources used to obtain relevant information include various issues of *Statistical Yearbook of Bangladesh* and *Yearbook of Agricultural Statistics of Bangladesh.*

Cost of Fertilizer

Fertilizer costs are defined as the sum of expenditures on fertilizers. Three types of fertilizer – Urea, Triple Super Phosphate, and Muriate of Potash, which are used in the Bangladesh agricultural sector are considered. The data on annual consumption of Urea, Triple Super Phosphate, and Muriate of Potash (in thousand metric tons) are used in this study without any modifications. Considering the prices of fertilizer by type, the costs of fertilizer are derived as the per year consumption of fertilizers multiplied by the corresponding year's prices (Taka per ton). Data on quantity and prices of fertilizers are collected from various issues of *Statistical Yearbook of Bangladesh* and an unofficial database on the agricultural sector in Bangladesh (Khalil, 1991).

Cost of Irrigation

Irrigations cost are defined as the sum of expenses on individual irrigation methods. In Bangladesh, three types of modern irrigation methods play a dominant role. These are low lift pumps (LLPs), deep tubewells (DTWs), and shallow tubewells (STWs). Area irrigated by various methods in terms of acres is used in this study. Since no systematic time series data on price of irrigation are available from official sources, some selected unofficial studies are used to obtain data on price of irrigation for some years. From these unofficial sources, per acre operating and maintenance cost are constructed.

Due to non-availability of particular yearly data on prices of irrigation the growth rates are obtained from the available data and used to approximate values for the missing years. Thus to obtain the costs of irrigation, the area irrigated by various methods are multiplied by operating and maintenance cost paid by farmers for the respective methods. Data on irrigation are obtained from various issues of the *Statistical Yearbook of Bangladesh*, Khalil (1991), Quasem (1987), Osmani and Quasem (1985), and Bangladesh Agriculture University (BAU,1985). Finally, total cost on irrigation is obtained as the sum of the expenditures on these inputs. Cost share of irrigation is obtained by dividing total cost by cost of irrigation.

Agricultural Output in Bangladesh

In this study, time series data on price and quantities of output are taken almost entirely from official government sources, that is, various issues of the *Statistical Yearbook of Bangladesh*, *Yearbook of Agricultural Statistics*, and *Monthly Statistical Bulletins*. Output classification used in this study is presented in Table 5.1. From this table, it is seen that the data on agricultural output include cereals, cash crops, pluses, oil seeds, vegetables, fruits and spices. Among the cereals, rice and wheat are taken, while among the cash crops jute and sugarcane is used in this study. In case of pulses, *masur,* gram, *mashkalai,* and *moong* are included. The data on chillies, onion, and garlic have been chosen from the spices group. Rape and mustard, *til*, linseed and coconut are counted for oil seeds group. Among the vegetables, brinjal, tomato, cauliflower and radish are included while potato is included as a tuber crop. In case of fruits, data on banana, mango, jackfruit and pineapple are taken. Tea is also included here. In case of prices of output, mainly the harvest price of major agricultural crops are used and some data are constructed according to the requirements of the estimation procedures. In constructing the quantity index of all agricultural output, composition of 25 crops are considered to obtain the aggregate crop index.

Table 5.1: Output Classification Used in this Study

Agricultural Output	Crops
Cereals	Rice and Wheat
Cash Crops	Jute and Sugarcane
Pulses	*Masur*, Gram, *Mashkalai* and *Moong*
Spices	Chillies, Onion and Garlic
Oil seeds	Rape and mustard, *Til*, Linseed and Coconut
Vegetables	Brinjal,Tomato,Cauliflower and Radish
Tuber Crops	Potato
Fruits	Banana, Mango, Jackfruit and Pineapple and Tea

Agricultural output consists of both the crop and non-crop output. Among crops, rice is dominant and other important crops are jute, sugarcane, tea, tobacco, oilseeds, potato and pulses. Non-crop agriculture means livestock, fisheries, forestry and other related activities and these sub sectors made comparatively little contribution to the output growth. In Bangladesh, since crop production dominates the agriculture sector, the time series data on price and quantity of crop sector is readily available in most of the official statistics of Bangladesh.

5.2 Indexing Procedures

There are two well-known indexing methods relevant for our study- the Laspeyres index, and the Divisia index. For constructing the price and quantity indexes by using the yearly data, Divisia indexing method is employed in this study because this is consistent with the translog cost function. The description of the two indexing procedures are presented below.

The Laspeyres Index

Like other countries, the official government source in Bangladesh, the Bangladesh Bureau of Statistics (BBS) uses the Laspeyres indexing method. Laspeyres formula can be written thus,

$$I_L = \frac{P_n Q_o}{P_o Q_o} \tag{5.1}$$

where I_L= index, P_n = current price, P_o = base price and Q_o =base period quantity. In the modified form, the formula is given as

$$I_L = \frac{\sum (P_n/P_o) w_i}{\sum W} \times 100 \tag{5.2}$$

where w_i = weight of the individual item, and W = weight of the group.

A glance at equation (5.1) and equation (5.2) reveals that both the current and base period prices are needed to construct the price indexes while only the base period quantities are required. In the Laspeyres formula, it is only possible to compare the current value of the base period quantity to the base period value of the base period quantity.

The Laspeyres method ignores the changes in different sub components and, as a result, estimated index may be biased. Laspeyres indexing procedure implicitly assume all inputs to be perfect substitutes which obviously they are not. This is especially important for the agricultural sector which is characterized by fluctuations in both production and prices. In spite of the shortcomings of the Laspeyres index, it is widely used as a general-purpose indexing tool and constitutes the basis of most official statistics appearing in government publications.

The Divisia index tries to overcome the above stated problems. Tornqvist (1936) introduced the discrete approximation to the Divisia index as a flexible weight method. The Tornqvist index numbers are used to correct for changing input quality (Gollop and Jorgenson, 1980). In estimating the translog cost function, Berndt and Wood (1975), Griffin (1981), Norsworthy and Malmquist (1983), Aw and Roberts (1985), and Kuroda (1987) have used the Divisia indexing method in their studies. The Divisia indexing method has been chosen because it uses a flexible weighting scheme as against the widely used Laspeyres and Paasche indexes which use a fixed weighting scheme.

The Divisia Index

The Divisia index in its usual form is presented in continuous terms (Divisia, 1928). To construct price and quantity indexes using yearly data, the following discrete approximation to the Divisia index given by Tornqvist (1936) is used:

$$l_nP_t - l_nP_{t-1} = \sum \overline{W}_{it}(l_nP_{it} - l_nP_i, t-1) \qquad (5.3)$$

$$l_nQ_t - l_nQ_{t-1} = \sum \overline{W}_{it}(l_nq_{it} - l_nq_i, t-1) \qquad (5.4)$$

where P = Price

Q = Quantity

i = Sub components

$\overline{W}_{it}$ = average of the relative shares in any two adjacent periods.

The weight $\overline{W}_{it}$ =embodies the changing importance of the sub components. For averaging, the arithmetic average is employed for our calculations which is also the general practice (Brown,1978 ; Islam,1982) .

Based on the Divisia indexing method, the price indexes for the various inputs are constructed using the following components and sub components:

1. Land
2. Labour
3. Fertilizer
   - (i) Urea
   - (ii) Triple Super Phosphate (TSP)
   - (iii) Muriate of Potash (MP)

4. Irrigation (i) Low Lift Pump (LLP)

(ii) Deep Tubewell (DTW)

(iii) Shallow Tubewell (STW)

.Data sources of these input categories were presented earlier.

5.3 Cost Share Estimates and Divisia Price Indexes of Inputs

The cost shares of four inputs are presented in Table 5.2. In analyzing factor substitution, the cost shares of inputs are needed to estimate the translog cost function. The first column of Table 5.2 shows the cost shares of land. From this table it is observed that the cost shares of land did not increase significantly but it fluctuated several times. In the early years of the sample period, slow increase in the cost shares of land was found. But from 1979 to 1983 it rose. From 1984, this trend slackened. In Bangladesh, a slight increase in the quantity of cultivated land was observed during the study period. Coupled with this, extreme increase in land price may have caused an increase in the cost share of land.

The cost share of labour in total cost has gradually decreased during the period considered. Although the daily wages of agricultural labour has increased over time but its share in total cost has declined over time. The declining tendency in labour cost share happend due to the transfer of agriculture labour force from the traditional sector to the non-agricultural sector. Decrease in the share of labour implies the presence of labour saving technology in Bangladesh agriculture.

Table 5.2: Cost Shares of Inputs for Bangladesh Agriculture, 1973 – 1995

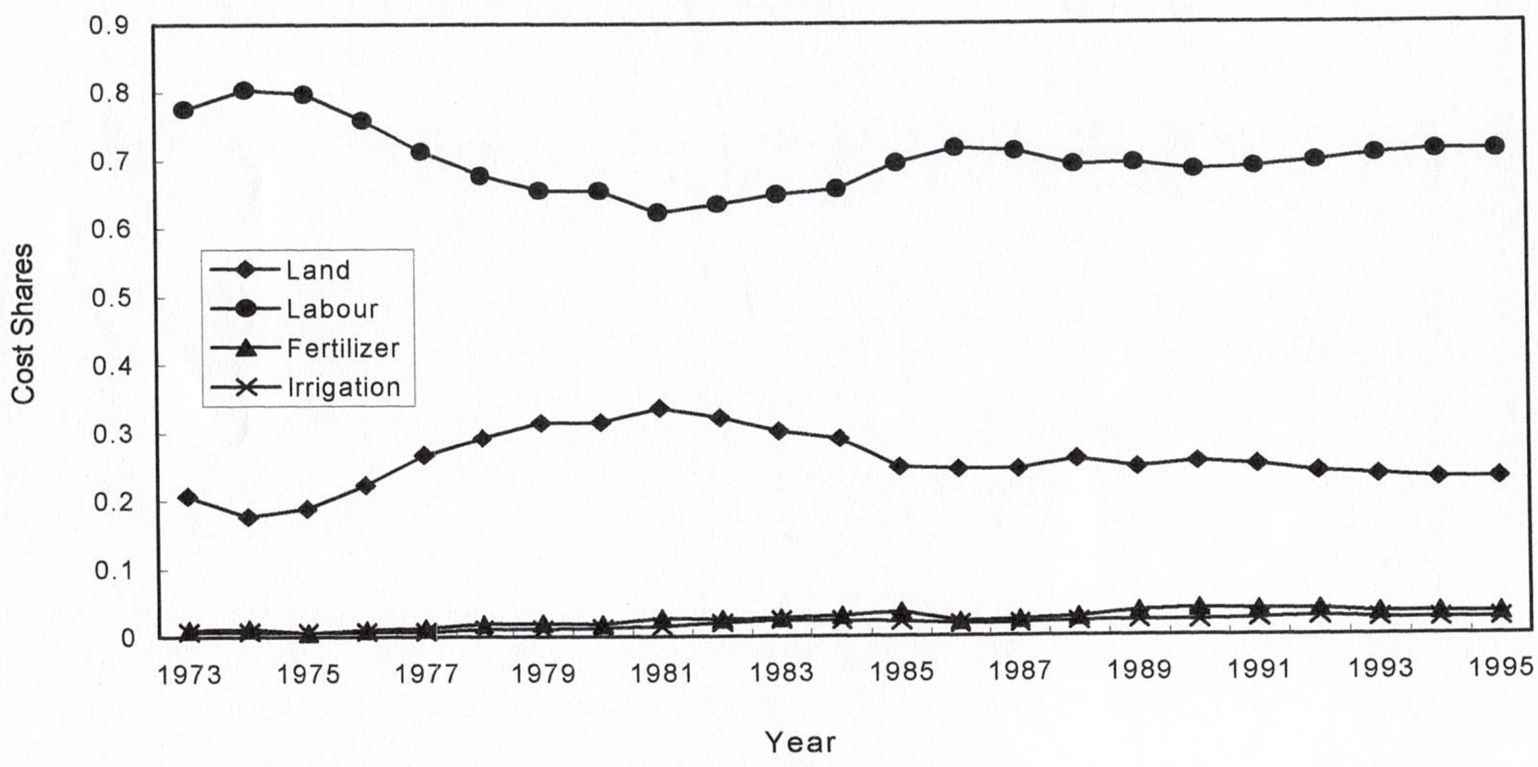
Year	Land	Labour	Fertilizer	Irrigation
1973	.2073	.7753	.0100	.0074
1974	.1770	.8035	.0122	.0074
1975	.1890	.7977	.0064	.0069
1976	.2231	.7590	.0103	.0076
1977	.2672	.7124	.0129	.0075
1978	.2922	.6779	.0188	.0111
1979	.3141	.6549	.0196	.0114
1980	.3149	.6546	.0178	.0126
1981	.3356	.6222	.0269	.0153
1982	.3212	.6341	.0252	.0196
1983	.3015	.6481	.0263	.0241
1984	.2905	.6561	.0301	.0233
1985	.2484	.6951	.0350	.0216
1986	.2447	.7161	.0213	.0179
1987	.2449	.7123	.0243	.0185
1988	.2597	.6917	.0276	.0211
1989	.2473	.6936	.0360	.0231
1990	.2551	.6839	.0391	.0219
1991	.2504	.6875	.0374	.0247
1992	.2408	.6963	.0374	.0254
1993	.2350	.7065	.0339	.0246
1994	.2304	.7118	.0334	.0244
1995	.2307	.7117	.0329	.0247

The cost share of fertilizer gradually increased during the sample period. Since independence, consumption of fertilizer has risen sharply as reported by Bangladesh Bureau of Statistics (BBS). In Bangladesh, government determines the prices of fertilizer and its supply. Though prices of fertilizer increased over time but it is considered quite moderate compared to prices of other inputs like land and labour. Thus, remarkable increase in consumption of fertilizer and a quite moderate increase in the fertilizer prices might have caused the increasing tendency of its cost shares. This tendency may suggest that fertilizer using technology prevailed in Bangladesh agriculture.

The cost share of irrigation rose steadily during the study period. In the early years of the sample period, the cost share of irrigation was very low but over time it gradually increased. Area irrigated by modern method has increased and the increasing tendency of per acre operating and maintenance cost of irrigation equipment may have caused the increasing trend in the cost share of irrigation. The gradual increase in irrigation cost share may indicate the presence of irrigation using technical change in Bangladesh agriculture.

The cost shares of inputs are graphically displayed in Figure 5.1. From this figure, it is observed that the cost share of labour tended to fall from 1976 to 1984 and from 1985 it remained quite stable while the cost shares of land tended to rise steadily during 1976-1984 period and from 1985 this trend slackened. The movements of the cost shares of fertilizer and irrigation remained nearly identical. An overall review indicates the cost share of labour registered the largest increase while increase in cost share of land held the second position.

Figure 5.1: Cost Shares of Inputs for Bangladesh Agriculture, 1973-1995



Divisia price indexes of input prices appear in Table 5.3. It is observed from this table that the highest increase occurred in case of land, which is followed by the price of irrigation. The price of land increased more than eleven times and the price of irrigation increased more than nine times. Though the price of labour and fertilizer increased, these were quite moderate compared to those of land and irrigation.

The price indexes of inputs are graphically presented in Figure 5.2. The sharp increase of land price and the gradual increase of irrigation price reached nearly same level in 1988. From 1989, land prices continued to increase at a faster rate. Both the prices of labour and fertilizer showed gradual increase but the price of fertilizer remained quite moderate as compared to other inputs.

5.4 Divisia Quantity Index of Output

The Divisia quantity indexes of output are presented in Table 5.4. The index of total agricultural production is constructed by combining all crops. As described earlier, only the crop sector is considered in this study while the non-crop agriculture like livestock, fisheries, forestry and other related activities are not included in this study. Data on cereals, cash crops, pulses, oilseeds, vegetables, fruits and spices are used. In all, twenty-five crops are considered to obtain the aggregate index. The price and quantity data of all twenty-five items of output are collected from the official sources such as the *Statistical Yearbook of Bangladesh*, *Yearbook of Agricultural Statistics* and *Monthly Statistical Bulletins*.

Table 5.3: Divisia Price Indexes of Agricultural Inputs in Bangladesh, 1973 – 1995 (1973 = 1.000)

Year	Land	Labour	Fertilizer	Irrigation
1973	1.000	1.000	1.000	1.000
1974	1.190	1.417	1.730	1.147
1975	1.690	1.917	1.703	1.350
1976	2.050	1.864	1.727	1.580
1977	2.730	1.886	2.083	1.823
1978	3.270	2.000	2.396	2.330
1979	3.940	2.305	3.064	2.654
1980	4.540	2.640	3.721	3.049
1981	5.360	2.964	4.649	3.655
1982	5.900	3.280	5.335	4.496
1983	5.920	3.612	5.347	5.147
1984	6.480	4.147	5.868	5.817
1985	6.740	5.179	6.747	6.287
1986	7.900	6.256	6.564	7.032
1987	8.000	6.765	6.182	7.152
1988	8.100	6.098	6.229	7.935
1989	8.180	6.363	6.660	7.939
1990	8.650	6.518	6.395	8.287
1991	9.082	6.909	6.465	8.498
1992	9.536	7.430	6.500	8.830
1993	10.013	7.951	6.559	9.071
1994	10.513	8.342	6.623	9.414
1995	11.039	8.669	6.647	9.725

Figure 5.2: Divisia Price Indexes of Agricultural Inputs in Bangladesh, 1973-1995 (1973 =1.000)

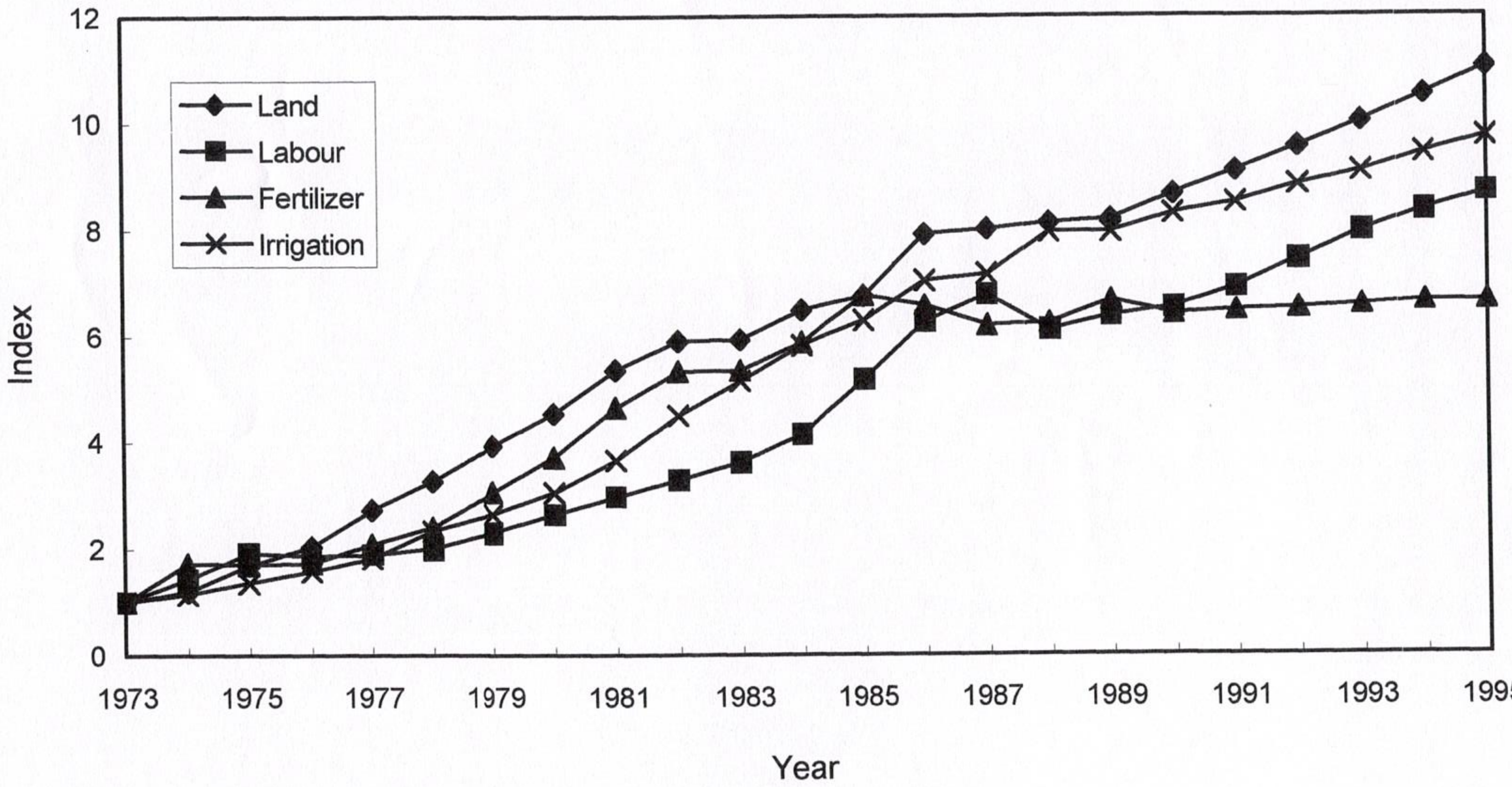


Table 5.4: Divisia Quantity Index of Agricultural Output in Bangladesh, 1973–1995 (1973 = 1.000)

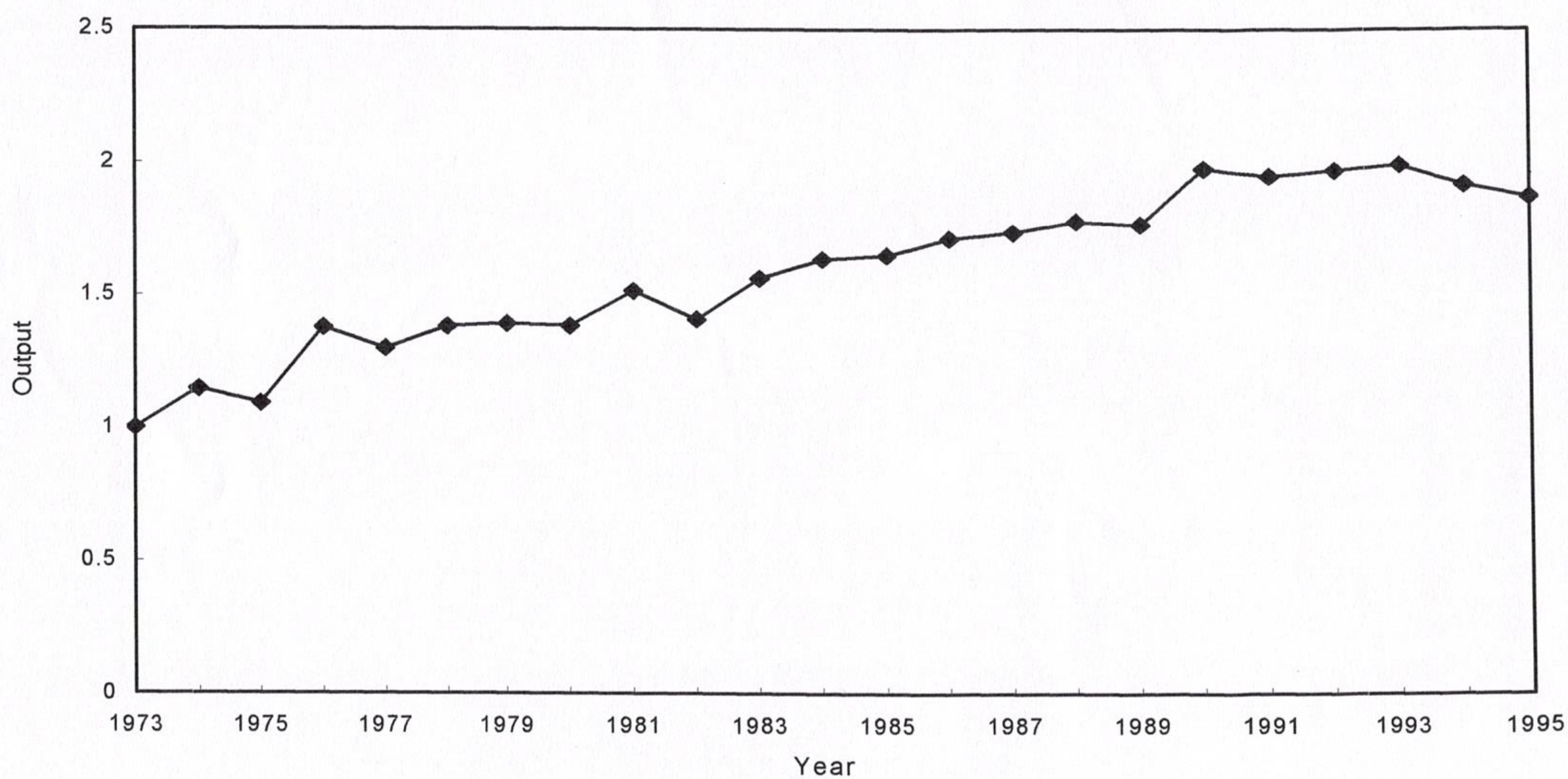
Year	Output
1973	1.000
1974	1.146
1975	1.091
1976	1.378
1977	1.299
1978	1.382
1979	1.391
1980	1.384
1981	1.516
1982	1.409
1983	1.564
1984	1.636
1985	1.651
1986	1.714
1987	1.736
1988	1.778
1989	1.766
1990	1.977
1991	1.947
1992	1.970
1993	1.991
1994	1.916
1995	1.869

It is seen from Table 5.4, that the output index of Bangladesh agriculture increased significantly relative to the base year of 1973. It rose from 1.000 in 1973 to 1.869 in 1995. Divisia quantity index of output is graphically displayed in Figure 5.3 which shows the increasing trend of agricultural output in Bangladesh.

5.5 Summary

This chapter contains a description of the data constructed for the translog model. Discussions on the characteristics of four inputs of land, labour, fertilizer, and irrigation and identification of the output categories are the prime issues of this chapter. The Divisia indexing methods is used due to its flexible weighting scheme. The cost shares of four inputs, the Divisia price indexes of inputs and Divisia indexes of output are constructed here. The price of land shows the highest increase followed by those of irrigation, labour, and fertilizer. The output index also shows an increasing trend.

Figure 5.3: Quantity Index of Agriultural Output in Bangladesh, 1973-1995 (1973 = 1.000)



CHAPTER 6

EMPIRICAL ESTIMATES OF FACTOR SUBSTITUTION AND TECHNICAL CHANGE IN BANGLADESH AGRICULTURE

This chapter deals with the nature of factor substitution and technical change in Bangladesh agriculture. Based on the translog cost function, the derived demand function or the cost share equations are used here. The estimated coefficients of the derived demand functions are then used to obtain the estimates of factor substitution, factor demand and the technical change.

Three modifications of the translog function are used in this study. These are (i) a homothetic structure without technical change (ii) a non-homothetic structure without technical change and (iii) a non-homothetic structure with technical change.

6.1 Derived Input Demand Functions

The translog cost function approach and its derived input demand functions were elaborately described in chapter 4. We recall the main estimating equation, which is given below.

$$S_i = a_i + \sum_{j}^{n} \gamma_{ij} \ln P_j + b_{Yi} \ln Y + \varphi_t P_i t \qquad (4.5)$$

where S_i is the share of the i-th input in total cost.

To study the three production structures, the above stated cost share equations are used for estimation. The cost share equations are estimated by imposing the adding up, zero homogeneity in prices and symmetry restrictions. These were stated in chapter 4.

6.2 Empirical Estimates for Bangladesh

6.2.1 Homothetic Structure without Technical Change

The estimates of the derived demand functions of the translog model are presented in Table 6.1. Eight of the nine estimated coefficients of input prices are statistically significant. The values of standard error of estimates (SEE) are found to be very low. The R^2 value of each equation ranges from 0.50 to 0.97. No R^2 value is given for the irrigation equation, since the irrigation equation is deleted from the estimation procedures. The Durbin-Watson statistics of each share equation falls within the indeterminate region. The estimated input price coefficients (the gamma coefficients) do not have any clear economic meaning, but these are used to calculate values of the Allen partial elasticities of substitution (AES) and own and cross price elasticities of demand (ED). The AES measures the ease with which one input is substituted for (or complemented by) another input in response to changes in their respective prices. The values of Allen partial elasticities of substitution are calculated from the estimated values of the coefficients of input prices and the cost shares of the relevant inputs by using the following relationship:

$$\sigma_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j} \qquad (4.10)$$

$$\sigma_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2} \qquad (4.11)$$

where σ_{ij} means the AES between factors i and j. It is recalled that the Allen partial elasticity of substitution (AES) are Symmetric, that is , $\sigma_{ij} = \sigma_{ji}$.

Table 6.1: Estimates of Derived Input Demand Functions, Homothetic Structure without Technical Change

Equation	Land	Labour	Fertilizer	Irrigation	Intercept	R^2	SEE	D-W
Land	2027** (16.76)	-.1864** (-22.79)	.0229** (3.23)	-.0391** (-3.34)	.2022 (73.02)	.9746	.006	1.02
Labour		2421** (20.09)	-.0084 (-1.18)	-.0472** (-4.35)	.7596 (250.30)	.9582	.009	.98
Fertilizer			-.0307** (-4.23)	.0163* (2.01)	.1916 (8.91)	.5000	.006	1.05
Irrigation				.0700	-.1534			

Note: The estimates were derived using the symmetry restrictions and the restriction that the sum of gamma coefficients is equal to zero for all i and j. In the irrigation equation, the estimated coefficient of irrigation were also derived by using the homogeneity restriction. Figures in parentheses indicate the asymptotic t-values. Coefficients significant at the 1% and 5% levels are denoted by two and one asterisk (s) respectively.

The estimated input price coefficients are converted into Allen partial elasticities of substitution (AES). The estimates of AES is presented in Table 6.2. Substitutability relationship prevailed for the pair of inputs land-fertilizer, labour-fertilizer and fertilizer-irrigation. Substitutability between land-fertilizer and labour-fertilizer can be viewed as sensible results. These results are compatible with the shift of agriculture labour force from the traditional agriculture sector to the non-agriculture sector, a slight increase in cultivated land and a remarkable increase in fertilizer consumption of the Bangladesh agriculture sector. The substitution relationship between fertilizer and irrigation is also viewed as a sensible and expected result.

The pair of inputs land-labour, land-irrigation and labour-irrigation displayed complementarity. The appearance of land-labour complementarity can be viewed as a common feature of Bangladesh agriculture because it is consistent with the observed decrease in the use of labour and a very moderate increase in cultivated land. The complementary relationship between land and irrigation is plausible because an increase in cultivated land may tend to bring more land under irrigation. But the complementary relationship between labour and irrigation is somewhat unexpected.

Estimates of own and cross price elasticities of demand (ED) show the responsiveness of any particular input to changes in its own prices or changes in other input prices.

Table 6.2: Estimates of Partial Elasticities of Substitution, Homothetic Structure without Technical Change

	Land	Labour	Fertilizer	Irrigation
Land	.1745	-.0343	5.6773	-7.6879
Labour		.0655	.5201	-2.8646
Fertilizer			-91.7916	41.8437
Irrigation				19.6875

Table 6.3: Estimates of Own and Cross Price Elasticities of Demand, Homothetic Structure without Technical Change

	Land	Labour	Fertilizer	Irrigation
Land	.0449	-.0240	.1419	-.1345
Labour	- .0088	.0458	.0130	-.0716
Fertilizer	1.4612	.3641	-2.2947	.7322
Irrigation	-1.9788	-2.005	1.0460	.3445

Table 6.3 contains the estimates of own and cross price elasticities of demand which were derived by using the following relationship:

$$ED_{ij} = S_j \sigma_{ij} \quad (4.12)$$

$$ED_{ii} = S_i \sigma_{ii} \quad (4.13)$$

where σ_{ij} denotes the AES between factors i and j and S_i is the share of i-th input in total cost. The cross-price elasticities of demand are not symmetric, that is $ED_{ij} \neq ED_{ji}$. The ED_{ij} and ED_{ji} will be symmetric if $S_i = S_j$.

It is observed from Table 6.3 that the own price elasticity of fertilizer is highest followed by that of irrigation, labour and land. The own price elasticity of demand of land is the lowest. A theoretically inadmissible positive own price elasticity was found in three cases. Such results are not uncommon in empirical research and were encountered by some earlier researchers (Baanante and Sidhu, 1980; Islam, 1982). Since the own price elasticity of demand of fertilizer is highest followed by that of irrigation it seems that the demand for fertilizer and irrigation are more responsive to own price changes than those of labour and land. Among the positive cross-price elasticities, fertilizer-land displays the highest positive value which indicates that the demand for fertilizer is more responsive to change in the price of land than that to other input prices.

6.2.2 Non-homothetic Structure without Technical Change

Estimates of the coefficients of the derived demand functions based on a non-homothetic structure without technical change are presented in Table 6.4. In this case, input demand is regarded a function of both input prices and the level of output while in the homothetic case, only input prices are considered. Technical change is not considered in this structure.

As reported in Table 6.4, of the nine estimated coefficients of input prices, six were found statistically significant. The values of R^2 are quite high and ranged from 0.84 to 0.97. All the estimated output coefficients are statistically significant and it is significantly different from zero, which implies the evidence of non-homotheticity. It seems that the inclusion of output in the derived demand function for Bangladesh agriculture is relevant and justifiable. Economically, this means that scale effect is important and the size of farm influences the nature of factor substitution.

Now by including output, the revised values of Allen partial elsticities of substitution are presented in Table 6.5. Here substitution relationship is obtained between the pair of inputs: land-fertilizer, labour-fertilizer and fertilizer-irrigation. All these pairs were also found as substitutes in the previous homothetic structure. Substitutability between land and fertilizer was also observed by Islam (1982) and Ali (1991) in their respective studies under the non-homothetic structure. The highest degree of substitutability is obtained between fertilizer and irrigation followed by that of land and fertilizer. Three pair of inputs, land-labour, land-irrigation and labour-irrigation showed complementarity which is similar to those observed in the homothetic structure.

Table 6.4: Estimates of Derived Input Demand Functions, Non-homothetic Structure without Technical Change

Equation	Land	Labour	Fertilizer	Irrigation	Output	Intercept	R^2	SEE	D-W
Land	.2071** (18.33)	-.1950** (-25.26)	.0042 (.60)	-.0163** (-2.52)	-.0200* (-2.14)	.2097 (46.89)	.9718	.006	1.00
Labour		.2231** (25.62)	-.0131* (-2.42)	-.0149** (-2.88)	-.0471** (-5.18)	.7788 (160.71)	.9700	.008	1.10
Fertilizer			.0008 (.11)	.0081 (1.47)	.0405** (5.64)	.0054 (1.77)	.8401	.003	1.29
Irrigation				.0231	.0266	.0061			

Note: Figures in parentheses indicate t-values. Figures without t-values were obtained by using the adding up restrictions.

Table 6.5: Estimates of Partial Elasticities of Substitution, Non-homothetic Structure without Technical Change

	Land	Labour	Fertilizer	Irrigation
Land	.2410	-.0820	1.6617	-2.6212
Labour		.9507	.2515	-.2170
Fertilizer			-39.2916	21.3437
Irrigation				19.6875

Table 6.6: Estimates of Own and Cross Price Elasticities of Demand, Non-homothetic Structure without Technical Change

	Land	Labour	Fertilizer	Irrigation
Land	.0620	-.0574	.0415	-.0458
Labour	-.0211	.6655	.0062	-.0037
Fertilizer	.4277	.1760	-.7322	.3735
Irrigation	-.6746	-.1519	.5335	.3445

The own and cross-price elasticities of demand for the non-homothetic structure are shown in Table 6.6. These show some differences from the homothetic structure. This table shows the highest own price elasticity of demand for fertilizer followed by those of labour, irrigation and land. Land displayed the lowest estimate as in the previous homothetic structure. All estimates of own price ED are found to be less than one.

6.2.3 Non-homothetic Structure with Technical Change

The estimated coefficients of the derived demand functions for non-homothetic structure with technical change are presented in Table 6.7. Seven of the nine estimated price coefficients are statistically significant. The standard error of estimates is very low. The R^2 values are very high and range from .89 to .97. The Durbin-Watson statistic for each equation falls within the indeterminate region. Three estimated coefficients of the output variable are significantly different from zero which imply the presence of non-homotheticity. It means that the level of output has some influence on the estimates of factor substitution. However, none of the coefficients of the output variable are found to be statistically significant. This result appears weak relatively to the previous structure.

Among the three estimated share equations, two estimated coefficients on the time variable are statistically significant at the five percent level of significance. That is, there is some evidence of technical changes.

Table 6.7: Estimates of Derived Input Demand Functions, Non-homothetic Structure with Technical Change

Equation	Land	Labour	Fertilizer	Irrigation	Time	Output	Intercept	R^2	SEE	D-W
Land	.2031** (19.29)	-.1913** (-23.20)	-.0020 (-.31)	-.0100** (-2.60)	-.1578* (-1.94)	.0263 (.94)	.2093 (46.05)	.9729	.006	.93
Labour		.2242** (23.78)	-.0180** (-3.52)	-.0150** (-4.92)	-.0467 (-.53)	-.0348 (-1.16)	.7766 (156.74)	.9742	.007	1.29
Fertilizer			-.0097 (1.44)	.0103** (2.64)	.1017* (2.10)	.0115 (.74)	.0072 (2.74)	.8954	.003	1.65
Irrigation				.0147	.1028	-.0030	.0069			

Note: Figures in parentheses indicate t-values. Figures without t-values were obtained by using the adding up restrictions.

In the land and labour equations, the sign of the time coefficients are both negative. This implies that both land and labour saving technological changes happened during the study period.. Time coefficients are found to be positive in the fertilizer and the irrigation equation. These results are expected and are consistent with the present nature of input use in the Bangladesh agriculture sector.

As before, the estimated input price coefficients are converted into Allen partial elasticities of substitution (AES) and these AES are reported in Table 6.8. The table indicates that among the six pairs of inputs, both land-fertilizer and fertilizer-irrigation input pairs appeared as substitutes. Complementarity relationship prevailed for other four pair of inputs. It can be noted that both the land-fertilizer and fertilizer-irrigation input pairs displayed substitutability relationship in three structures of the translog model. The appearance of complementarity of land-labour, land-irrigation and labour-irrigation input pairs are common in these three structures of the translog model. Here an important exception is the relationship between labour and fertilizer, which appeared as substitutes in the earlier two structures but now shows complementarity in the non-homothetic structure with technical change cases. A high degree of substitutability between fertilizer and irrigation is common in both homothetic and non-homothetic structures.

Table 6.8: Estimates of partial Elasticities of Substitution, Non-homothetic Structure with Technical Change

	Land	Labour	Fertilizer	Irrigation
Land	.1805	-.0615	.6929	-1.2212
Labour		.0290	-.0284	-.2252
Fertilizer			-56.7916	26.8437
Irrigation				-8.3125

Table 6.9: Estimates of Own and Cross Price Elasticities of Demand, Non-homothetic Structure with Technical change

	Land	Labour	Fertilizer	Irrigation
Land	.0464	-.0430	.0173	-.0213
Labour	-.0158	.0203	-.0007	-.0039
Fertilizer	.1783	-.0198	-1.4197	.4697
Irrigation	-.3143	-.1576	.6710	-.1454

The estimated price elasticities of input demand (ED) are given in Table 6.9. Here except the value of fertilizer, the absolute values of all own price elasticities of demand are less than one and this implies inelastic demand for most farm inputs. The highest value of own price ED was found for fertilizer. Similar result was also observed in the previous two structures. Here own price ED of fertilizer is the highest followed by those of irrigation, land and labour.

6.3 Trends of Input Relationhips

In this section, the relationship between various inputs is examined. This is done over the period from 1973 to 1995. Since independence, significant changes have occurred in input relations over time. It is interesting to note that, in case of AES, most of these changes declined over time but these changes have intensified somewhat in the latter years. Based on the three structures of the translog model, input relationship were assessed by considering the signs and magnitudes of the translog estimates of AES and cross elasticities of input demand. Since the entire study period is considered, it enabled us to know whether fertilizer-irrigation substitution relationship declined significantly in the latter years in spite of the high irrigation cost due to high energy prices.

6.3.1 Estimates Based on the Homothetic Structure without Technical Change

Estimates of Allen partial elasticity of substitution for the period 1973 to 1995 are presented in Table 6.10. Differences exist in sign and magnitude of AES values. Both substitutability and complementarity relationships were found to exist. The estimate for the period 1973 to 1995 showed some decline for all input pairs

Table 6.10: Estimates of Elasticities of Substitution for the Homothetic Structure without Technical Change, 1973-1995

Year	N – L	N – F	N – I	L – F	L – I	F – I
1973	-.598	.581	-.874	-.001	-.069	163.740
1974	-1.410	.800	-1.206	.002	-.064	110.120
1975	-.998	.675	-1.058	-.005	-.066	399.027
1976	-.343	.506	-.751	-.001	-.072	154.381
1977	.055	.369	-.520	.002	-.082	98.532
1978	.137	.333	-.420	.009	-.086	46.709
1979	.196	.295	-.360	.010	-.093	43.012
1980	.199	.287	-.354	.008	-.091	52.153
1981	.199	.283	-.302	.022	-.097	23.095
1982	.167	.300	-.318	.019	-.086	26.445
1983	.099	.339	-.350	.021	-.075	24.482
1984	.050	.375	-.383	.026	-.074	18.765
1985	-.223	.512	-.547	.033	-.067	13.923
1986	-.187	.469	-.580	.013	-.067	36.768
1987	-.199	.481	-.576	.018	-.067	28.366
1988	-.100	.446	-.498	.022	-.068	22.162
1989	-.243	.520	-.546	.034	-.065	13.219
1990	-.183	.505	-.515	.039	-.069	11.222
1991	-.227	.515	-.525	.037	-.064	12.314
1992	-.323	.550	-.569	.036	-.061	12.332
1993	-.369	.559	-.603	.031	-.060	14.909
1994	-.422	.576	-.631	.030	-.059	15.342
1995	-.417	.573	-.628	.030	-.058	15.810

Note: N – L = Land-Labour, N – F = Land-Fertilizer, N – I = Land-Irrigation, L – F = Labour-Fertilizer, L – I = Labour-Irrigation, F – I= Fertilizer-Irrigation except the relationship of the labour-fertilizer pair. The extent of labour-fertilizer substitution showed a gradual increase over the latter period, while the substitution between fertilizer and irrigation showed sustained decline over the latter period. The AES between labour and irrigation showed a decline over the latter years.

Unlike the estimates of elasticity of substitution, the cross elasticity estimates are not symmetric. Hence, two tables are presented rather than one. The estimates of cross elasticities of input demand are given in Table 6.11and 6.12. From these tables it is observed that there are considerable differences in sign and magnitude of estimates between the early years and latter years.

From Table 6.11, it is observed that significant changes have occurred over time. The cross elasticity of demand (ED) for fertilizer-irrigation has markedly declined over the latter years, but the ED for land-fertilizer, land-irrigation, labour-fertilizer and labour-irrigation displayed an increasing trend. The Table 6.12 also indicates that the ED for irrigation and fertilizer significantly declined but the magnitude differs from those in the earlier Table 6.11.

Table 6.11: Estimated Cross-Elasticities of Input Demand for the Homothetic Structure without Technical Change, 1973 – 1995

Year	N-L	N-F	N-I	L-F	L-I	F-I
1973	-0.4633	0.0058	-0.0065	0.0000	-0.0005	1.2117
1974	-1.1331	0.0098	-0.0089	0.0000	-0.0005	0.8149
1975	-0.7958	0.0043	-0.0073	0.0000	-0.0005	2.7533
1976	-0.2603	0.0052	-0.0057	0.0000	-0.0005	1.1733
1977	0.0394	0.0048	-0.0039	0.0000	-0.0006	0.7390
1978	0.0928	0.0063	-0.0047	0.0002	-0.0010	0.5185
1979	0.1281	0.0058	-0.0041	0.0002	-0.0011	0.4903
1980	0.1303	0.0051	-0.0045	0.0001	-0.0011	0.6571
1981	0.1238	0.0076	-0.0046	0.0006	-0.0015	0.3533
1982	0.1062	0.0076	-0.0062	0.0005	-0.0017	0.5183
1983	0.0642	0.0089	-0.0084	0.0005	-0.0018	0.5900
1984	0.0326	0.0113	-0.0089	0.0008	-0.0017	0.4372
1985	-0.1548	0.0179	-0.0118	0.0012	-0.0014	0.3007
1986	-0.1336	0.0100	-0.0104	0.0003	-0.0012	0.6581
1987	-0.1420	0.0117	-0.0107	0.0004	-0.0012	0.5248
1988	-0.0694	0.0123	-0.0105	0.0006	-0.0014	0.4676
1989	-0.1687	0.0187	-0.0126	0.0012	-0.0015	0.3054
1990	-0.1254	0.0198	-0.0113	0.0015	-0.0015	0.2458
1991	-0.1562	0.0192	-0.0130	0.0014	-0.0016	0.3041
1992	-0.2249	0.0206	-0.0144	0.0014	-0.0015	0.3132
1993	-0.2606	0.0189	-0.0148	0.0011	-0.0015	0.3668
1994	-0.3004	0.0193	-0.0154	0.0010	-0.0014	0.3743
1995	-0.2970	0.0188	-0.0155	0.0010	-0.0014	0.3905

Table 6.12: Estimated Cross-Elasticities of Input Demand for the Homothetic Structure without Technical Change, 1973 – 1995

Year	L – N	F – N	I – N	F – L	I – L	I – F
1973	-0.1239	0.1205	-0.1812	-0.0008	-0.0535	1.6374
1974	-0.2496	0.1416	-0.2135	0.0017	-0.0513	1.3435
1975	-0.1885	0.1276	-0.2000	-0.0041	-0.0523	2.5538
1976	-0.0765	0.1129	-0.1677	-0.0008	-0.0546	1.5901
1977	0.0148	0.0986	-0.1388	0.0011	-0.0588	1.2711
1978	0.0400	0.0972	-0.1227	0.0064	-0.0585	0.8781
1979	0.0615	0.0925	-0.1131	0.0068	-0.0607	0.8430
1980	0.0627	0.0905	-0.1116	0.0050	-0.0595	0.9283
1981	0.0668	0.0951	-0.1012	0.0134	-0.0606	0.6212
1982	0.0538	0.0965	-0.1021	0.0120	-0.0548	0.6664
1983	0.0299	0.1023	-0.1056	0.0133	-0.0487	0.6439
1984	0.0144	0.1089	-0.1113	0.0173	-0.0486	0.5648
1985	-0.0553	0.1272	-0.1358	0.0229	-0.0463	0.4873
1986	-0.0456	0.1149	-0.1419	0.0096	-0.0480	0.7832
1987	-0.0488	0.1178	-0.1412	0.0125	-0.0478	0.6893
1988	-0.0261	0.1158	-0.1295	0.0155	-0.0471	0.6117
1989	-0.0601	0.1286	-0.1350	0.0239	-0.0450	0.4759
1990	-0.0468	0.1289	-0.1314	0.0268	-0.0471	0.4388
1991	-0.0569	0.1289	-0.1315	0.0252	-0.0440	0.4605
1992	-0.0778	0.1325	-0.1370	0.0253	-0.0424	0.4612
1993	-0.0867	0.1313	-0.1418	0.0220	-0.0422	0.5054
1994	-0.0972	0.1328	-0.1453	0.0216	-0.0419	0.5124
1995	-0.0963	0.1322	-0.1448	0.0211	-0.0416	0.5201

Note: L – N = Labour–Land, F – N = Fertilizer–Land, I – N = Irrigation–Land,
F – L = Fertilizer–Labour, I – L = Irrigation–Labour, I – F = Irrigation–Fertilizer.

6.3.2 Estimates Based on the Non-homothetic Structure without Technical Change

The AES estimates for the period 1973-95 are reported in Table 6.13. This table shows the changes in signs of AES between the earlier and latter period. Four of the six estimates of the absolute values of the AES show a declining tendency over the latter period. The substitution between fertilizer and irrigation has declined in the latter period. The land-labour pair showed complementary relationship in the early period then they became substitute and again complement in the latter period. The land-fertilizer and labour-fertilizer substitutability showed evidence of an increasing tendency.

The estimated cross elasticities of demand are presented in Table 6.14 and 6.15. Both these tables also show considerable differences in signs and magnitudes from the previous structure. From the Table 6.14, it is observed that the ED for fertilizer-irrigation, and land-labour displayed a decreasing tendency whereas the land-fertilizer, land-irrigation and labour-fertilizer showed a rising tendency in the latter years. Here the magnitude of the ED for labour-irrigation remained more less the same during the entire period.

Table 6.15 shows the pair of irrigation-fertilizer and labour-land, which also declined as the earlier table but differences exist in magnitudes.

Table 6.13: Estimates of Elasticities of Substitution for the Non-homothetic Structure without Technical Change, 1973 – 1995

Year	N-L	N-F	N-I	L-F	L-I	F-I
1973	-0.798	0.146	-0.344	-0.009	-0.015	81.740
1974	-1.685	0.203	-0.478	-0.005	-0.014	55.027
1975	-1.238	0.151	-0.420	-0.013	-0.015	198.832
1976	-0.516	0.131	-0.293	-0.009	-0.016	77.088
1977	-0.065	0.107	-0.200	-0.008	-0.019	49.256
1978	0.036	0.114	-0.153	-0.001	-0.016	23.508
1979	0.108	0.105	-0.129	-0.001	-0.017	21.667
1980	0.112	0.099	-0.124	-0.003	-0.016	26.273
1981	0.123	0.117	-0.099	0.009	-0.014	11.763
1982	0.084	0.119	-0.097	0.007	-0.006	13.533
1983	0.004	0.133	-0.099	0.009	0.002	12.627
1984	-0.052	0.153	-0.113	0.015	0.001	9.714
1985	-0.362	0.209	-0.177	0.023	0.000	7.229
1986	-0.330	0.157	-0.199	0.004	-0.004	18.694
1987	-0.343	0.169	-0.196	0.008	-0.003	14.479
1988	-0.228	0.169	-0.160	0.013	-0.001	11.398
1989	-0.384	0.214	-0.173	0.025	0.002	6.892
1990	-0.316	0.218	-0.165	0.029	0.000	5.858
1991	-0.364	0.216	-0.161	0.027	0.004	6.451
1992	-0.471	0.228	-0.176	0.027	0.006	6.470
1993	-0.525	0.220	-0.190	0.022	0.005	7.774
1994	-0.584	0.224	-0.201	0.021	0.005	7.991
1995	-0.579	0.222	-0.199	0.020	0.005	8.234

Table 6.14: Estimated Cross-Elasticities of Input Demand for the Non-homothetic Structure without Technical Change, 1973 – 1995

Year	N-L	N-F	N-I	L-F	L-I	F-I
1973	-0.6185	0.0015	-0.0025	-0.0001	-0.0001	0.6049
1974	-1.3537	0.0025	-0.0035	-0.0001	-0.0001	0.4072
1975	-0.9878	0.0010	-0.0029	-0.0001	-0.0001	1.3719
1976	-0.3914	0.0013	-0.0022	-0.0001	-0.0001	0.5859
1977	-0.0464	0.0014	-0.0015	-0.0001	-0.0001	0.3694
1978	0.0245	0.0021	-0.0017	0.0000	-0.0002	0.2609
1979	0.0711	0.0021	-0.0015	0.0000	-0.0002	0.2470
1980	0.0735	0.0018	-0.0016	-0.0001	-0.0002	0.3310
1981	0.0763	0.0032	-0.0015	0.0003	-0.0002	0.1800
1982	0.0533	0.0030	-0.0019	0.0002	-0.0001	0.2652
1983	0.0029	0.0035	-0.0024	0.0002	0.0000	0.3043
1984	-0.0342	0.0046	-0.0026	0.0005	0.0000	0.2263
1985	-0.2516	0.0073	-0.0038	0.0008	0.0000	0.1562
1986	-0.2364	0.0033	-0.0036	0.0001	-0.0001	0.3346
1987	-0.2442	0.0041	-0.0036	0.0002	-0.0001	0.2679
1988	-0.1576	0.0047	-0.0034	0.0003	0.0000	0.2405
1989	-0.2662	0.0077	-0.0040	0.0009	0.0001	0.1592
1990	-0.2158	0.0085	-0.0036	0.0011	0.0000	0.1283
1991	-0.2505	0.0081	-0.0040	0.0010	0.0001	0.1593
1992	-0.3282	0.0085	-0.0045	0.0010	0.0001	0.1643
1993	-0.3706	0.0075	-0.0047	0.0007	0.0001	0.1912
1994	-0.4157	0.0075	-0.0049	0.0007	0.0001	0.1950
1995	-0.4120	0.0073	-0.0049	0.0007	0.0001	0.2034

Table 6.15: Estimated Cross-Elasticities of Input Demand for the Non-homothetic Structure without Technical Change, 1973 – 1995

Year	L – N	F – N	I – N	F – L	I – L	I – F
1973	-0.1654	0.0303	-0.0712	-0.0069	-0.0118	0.8174
1974	-0.2982	0.0359	-0.0847	-0.0041	-0.0111	0.6713
1975	-0.2340	0.0286	-0.0793	-0.0100	-0.0118	1.2725
1976	-0.1150	0.0291	-0.0655	-0.0070	-0.0120	0.7940
1977	-0.0174	0.0286	-0.0535	-0.0055	-0.0134	0.6354
1978	0.0105	0.0332	-0.0447	-0.0005	-0.0109	0.4420
1979	0.0341	0.0330	-0.0405	-0.0004	-0.0114	0.4247
1980	0.0354	0.0311	-0.0392	-0.0022	-0.0102	0.4677
1981	0.0412	0.0394	-0.0333	0.0058	-0.0086	0.3164
1982	0.0270	0.0383	-0.0311	0.0045	-0.0039	0.3410
1983	0.0013	0.0402	-0.0300	0.0061	0.0011	0.3321
1984	-0.0152	0.0446	-0.0328	0.0101	0.0006	0.2924
1985	-0.0899	0.0519	-0.0440	0.0162	0.0002	0.2530
1986	-0.0808	0.0385	-0.0487	0.0030	-0.0029	0.3982
1987	-0.0839	0.0414	-0.0481	0.0059	-0.0024	0.3518
1988	-0.0592	0.0438	-0.0417	0.0087	-0.0004	0.3146
1989	-0.0949	0.0530	-0.0428	0.0171	0.0016	0.2481
1990	-0.0805	0.0556	-0.0420	0.0199	0.0001	0.2291
1991	-0.0913	0.0542	-0.0404	0.0183	0.0030	0.2413
1992	-0.1135	0.0548	-0.0423	0.0186	0.0040	0.2420
1993	-0.1233	0.0518	-0.0448	0.0154	0.0035	0.2635
1994	-0.1346	0.0516	-0.0463	0.0150	0.0035	0.2669
1995	-0.1336	0.0511	-0.0460	0.0145	0.0038	0.2709

6.3.3 Estimates Based on the Non-homothetic Structure with Technical Change

The values of the Allen partial elasticities of substitution estimates for the period 1973-1995 are presented in Table 6.16. The signs of the estimates showed considerable variations. Five of the six estimates of the absolute values of the AES displayed a declining tendency. In this structure, the AES of fertilizer-irrigation showed significant decline in the latter years and the similar evidence was also found in the previous two structures. Substitution between land and fertilizer showed a large increase in the latter period. The increasing tendency of land-fertilizer pair is common in both non-homothetic structure but it differs from the homothetic structure.

To show the trends of Allen elasticities of substitution (AES) at a glance, the AES between six pairs of inputs are graphically presented here. Among the three structures used in this study, the estimates based on non-homothetic structure with technical change are graphically presented. In this study, we found that the non-homothetic structure with technical change can clearly characterize Bangladesh agriculture and it is also the most general model as it incorporates both nonhomtheticty and technical progress. In these figures, negative values of AES imply complementarity while the positive values indicate substitutability.

Figure 6.1 shows the AES between land and labour (N-L). It is seen that except for the middle years of the sample period, the AES of land and labour displayed complementarity.

Table 6.16: Estimates of Elasticities of Substitution for the Non-homothetic Structure with Technical Change, 1973 – 1995

Year	N-L	N-F	N-I	L-F	L-I	F-I
1973	-0.712	0.002	-0.197	-0.017	-0.015	103.740
1974	-1.567	0.005	-0.277	-0.013	-0.014	69.808
1975	-1.135	-0.022	-0.243	-0.020	-0.015	252.543
1976	-0.441	0.006	-0.167	-0.018	-0.016	97.825
1977	-0.013	0.020	-0.112	-0.017	-0.019	62.477
1978	0.079	0.041	-0.079	-0.011	-0.016	29.733
1979	0.146	0.042	-0.065	-0.012	-0.018	27.393
1980	0.150	0.036	-0.061	-0.015	-0.016	33.216
1981	0.155	0.062	-0.043	-0.003	-0.014	14.803
1982	0.120	0.059	-0.036	-0.005	-0.006	16.997
1983	0.045	0.065	-0.030	-0.002	0.001	15.807
1984	-0.008	0.080	-0.038	0.004	0.001	12.143
1985	-0.302	0.108	-0.075	0.013	0.000	9.025
1986	-0.268	0.054	-0.094	-0.005	-0.004	23.543
1987	-0.281	0.066	-0.091	-0.001	-0.004	18.204
1988	-0.173	0.077	-0.067	0.002	-0.001	14.286
1989	-0.323	0.113	-0.070	0.014	0.002	8.589
1990	-0.259	0.123	-0.068	0.019	0.000	7.297
1991	-0.305	0.117	-0.061	0.016	0.004	8.024
1992	-0.408	0.121	-0.067	0.017	0.006	8.043
1993	-0.458	0.108	-0.076	0.012	0.005	9.688
1994	-0.514	0.107	-0.082	0.011	0.005	9.964
1995	-0.509	0.105	-0.081	0.011	0.005	10.267

The AES between land and fertilizer (N-F) is graphically presented in Figure 6.2. Here increasing substitutability relationship between land and fertilizer was found except for the year 1975. This increasing substitutability in agriculture would imply that the remarkable consumption of fertilizers is associated with the moderate increase in total cropped area.

Figure 6.3 shows the AES between land and irrigation (N-I). Here, a declining complementarity relationship between land and irrigation was found. The declining complementarity between land and irrigation is consistent with moderate increase in total cropped area and significant use of modern irrigation methods in Bangladesh agriculture.

The AES between labour and fertilizer (L-F) is graphically presented in Figure 6.4. In the early years, the AES between labour and fertilizer appeared as complements while in the latter years, it was found to be substitutes and its substitutability showed substantial fluctuations. This substitutability trends is compatible with the observed decrease of agricultural labour force and increased consumption of fertilizers.

Figure 6.5 exhibits the AES between labour and irrigation (L-I). This pair of inputs displayed complementarity in the initial years but in the latter years it showed substitutability. Significant fluctuation was also observed.

The graphical presentation of AES between fertilizer and irrigation (F-I) is shown in Figure 6.6. In this figure, the pair of fertilizer and irrigation displayed

Figure 6.1: Elasticities of Substitution between Land and Labour (N-L) for the Non-homothetic Structure with Technical Change, 1973-1995

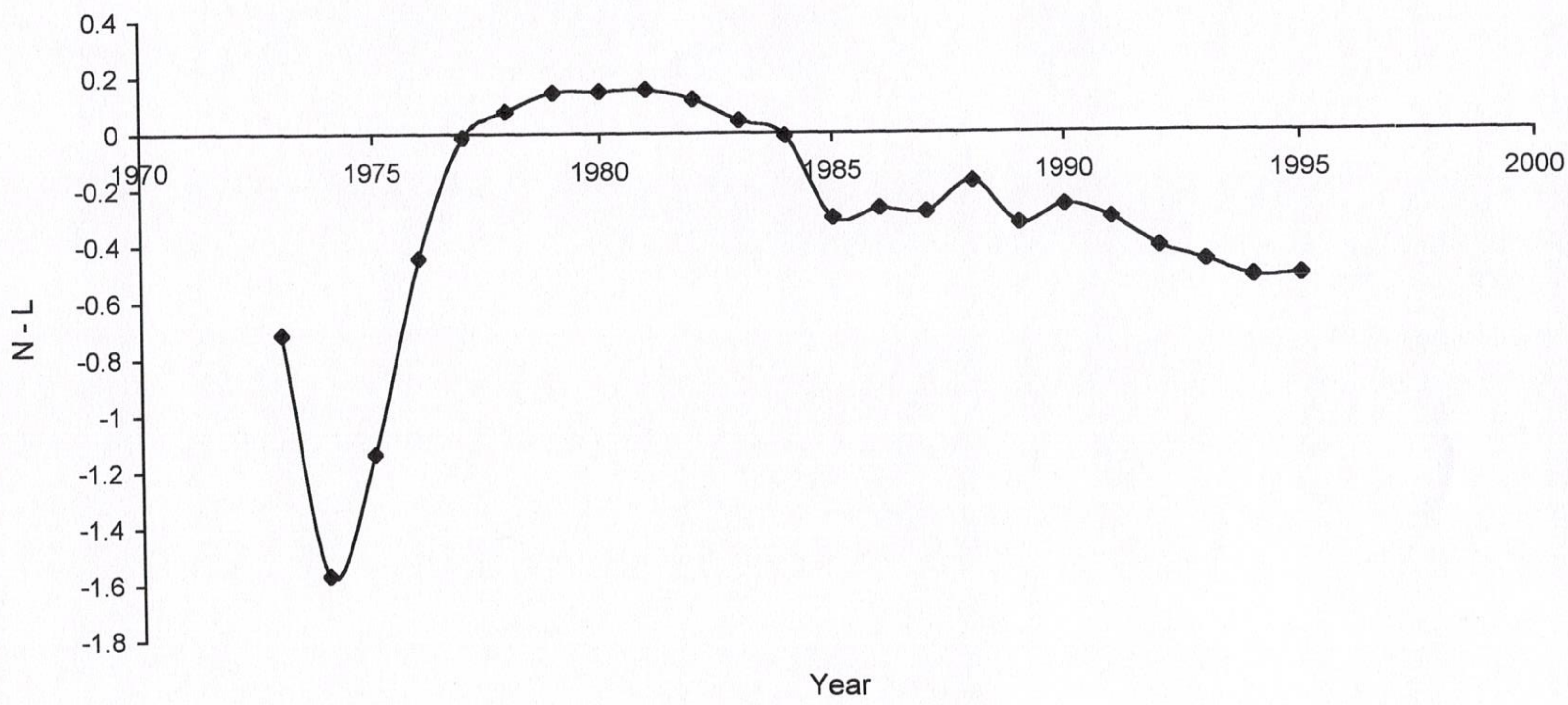


Figure 6.2: Elasticities of Substitution between Land and Fertilizer(N- F) for the Non-homothetic Structure with Technical Change, 1973-1995

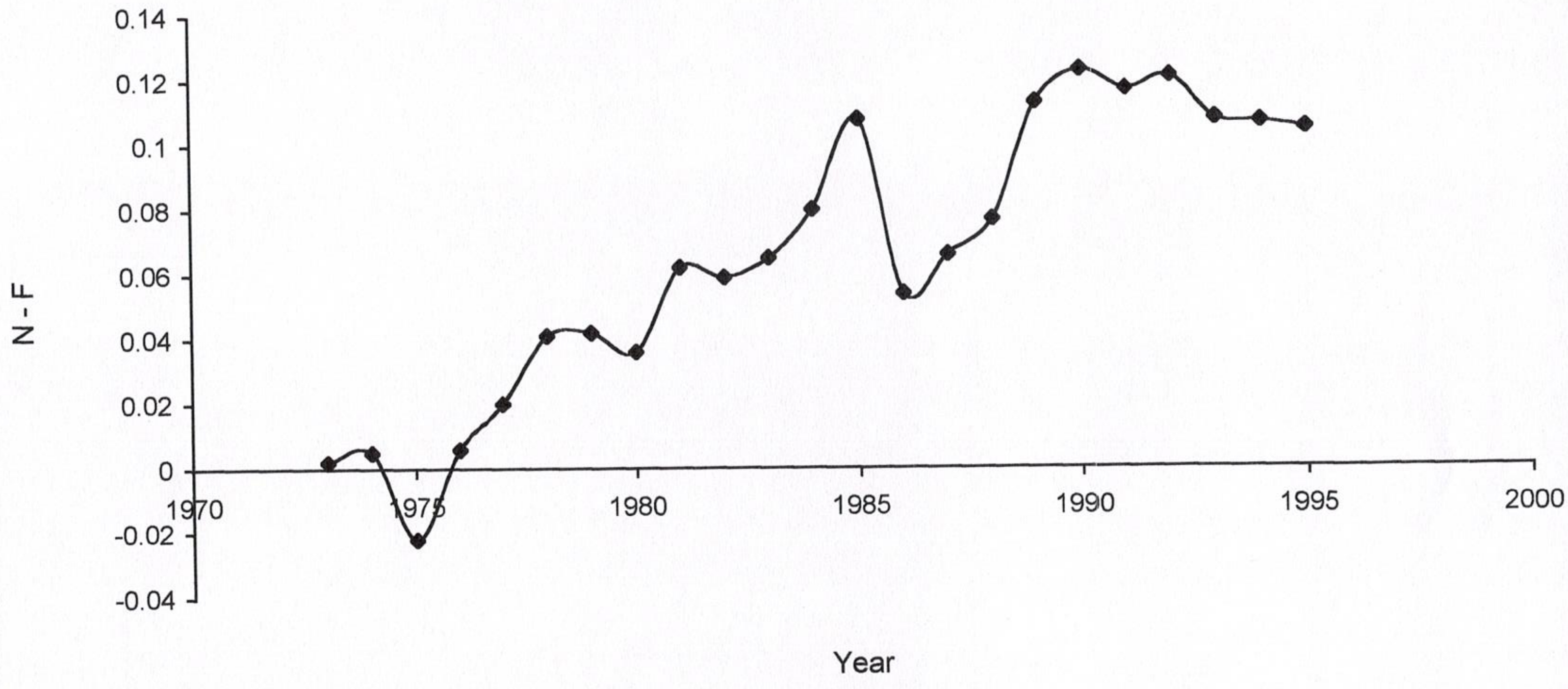


Figure 6.3: Elasticities of Substitution between Land and Irrigation (N - I) for the Non-homothetic Structure with Technical Change, 1973-1995

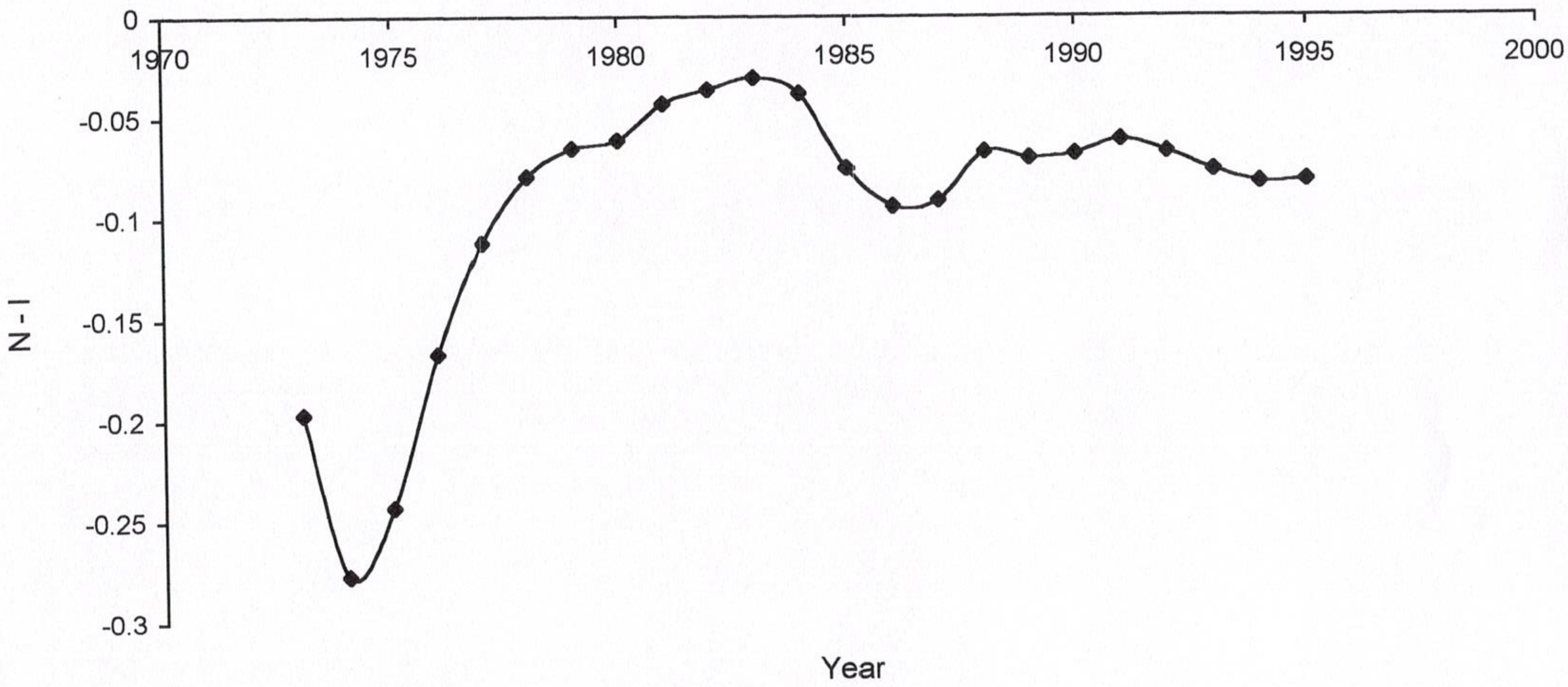


Figure 6.4: Elasticities of Substitution between Labour and Fertilizer (L- F) for the Non-homothetic Structure with Technical change, 1973-1995

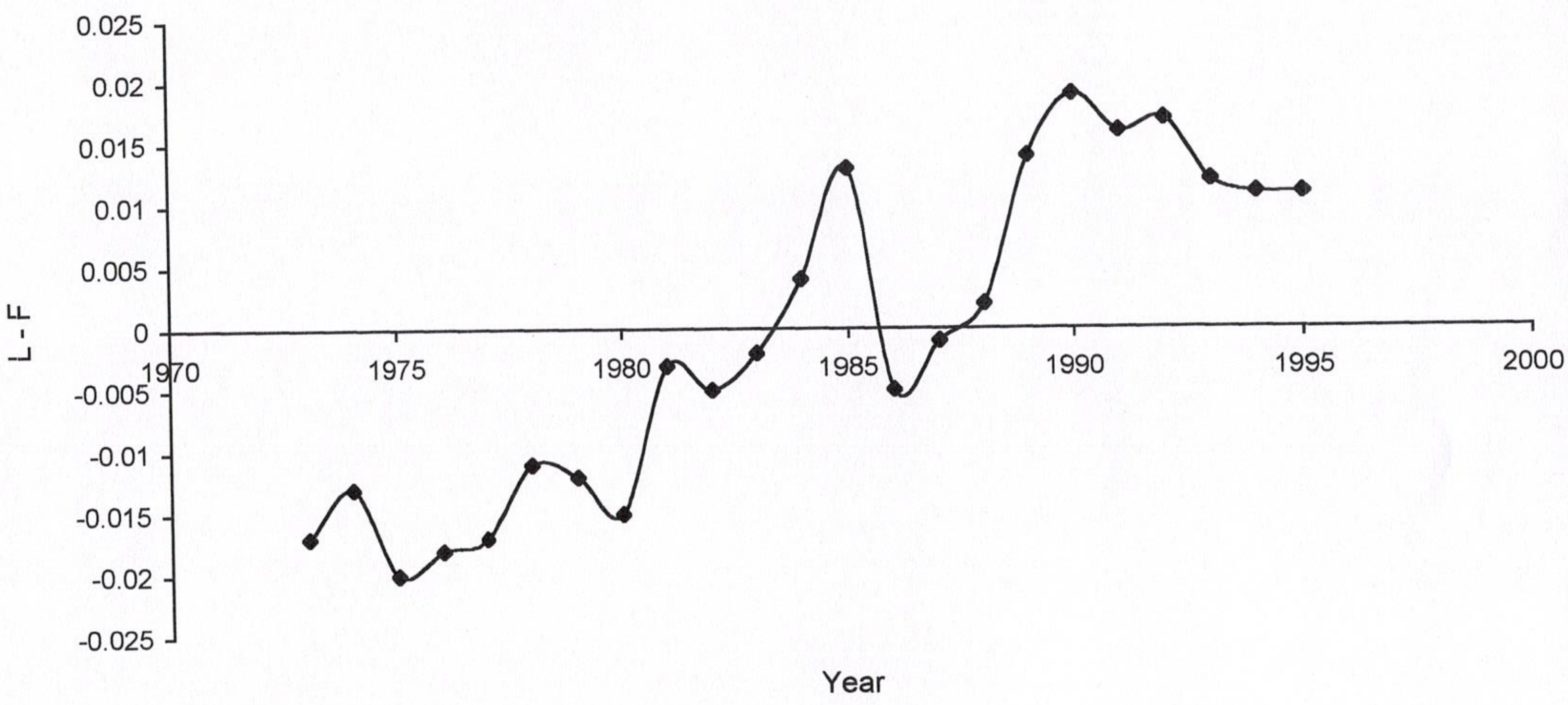


Figure 6.5: Elasticities of Substitution between Labour and Irrigation (L- I) for the Non-homothetic Structure with Technical Change, 1973-1995

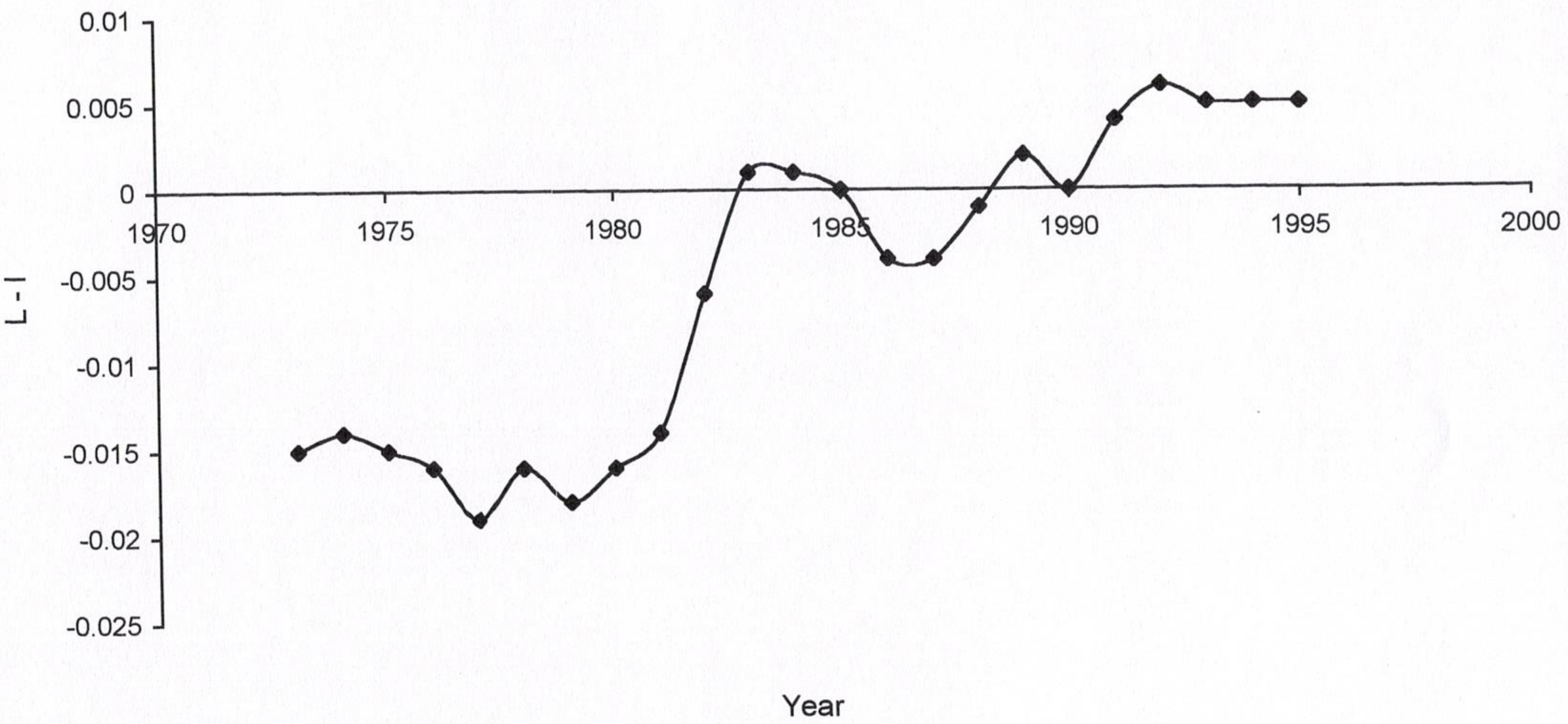
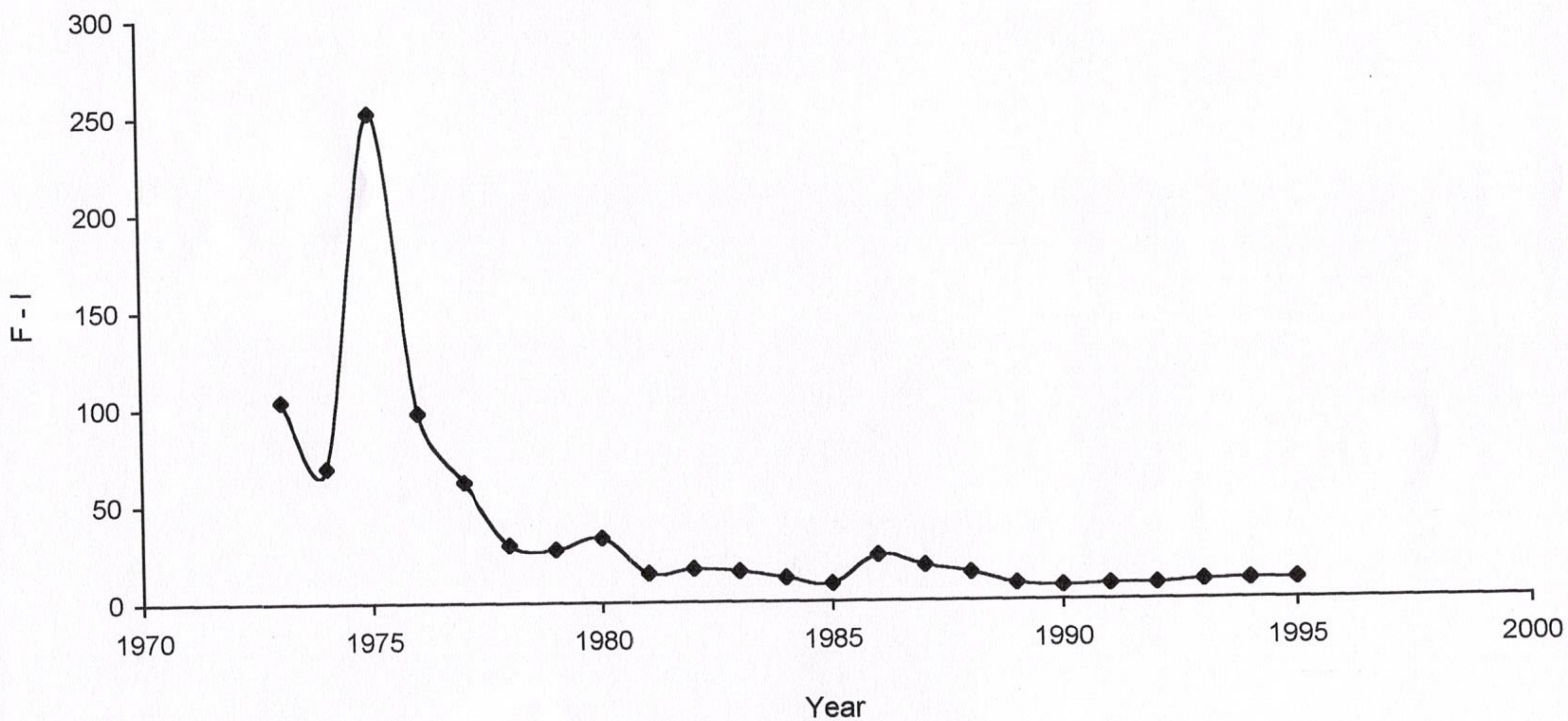


Figure 6.6: Elasticities of Substitution between Fertilizer and Irrigation (F- I) for the Non-homothetic Structure with Technical Change, 1973-1995



substitutability throughout but very high degree substitutability showed significant decline over the years. It means that, in the initial years farmers used more fertilizer than irrigation but over time both fertilizer and irrigation were used significantly and it might have caused the declining tendency of AES between fertilizer and irrigation.

The estimated input cross elasticities of demand in the non-homothetic structure with technical change are reported in Table 6.17 and 6.18. In Table 6.17, it is observed that two of the six estimates of ED showed some decline over the latter period where the absolute value of the ED for labour and irrigation is similar to those found in earlier non-homothetic structure. Table 6.18 shows the absolute value of the ED where estimates for all input pairs except fertilizer-land displayed a declining tendency.

Thus, from these estimates, it can be seen that considerable changes occurred in input relationships in Bangladesh agriculture over time. From these analysis, it can be noted that the estimates of AES between fertilizer and irrigation indicated a significant decline over the latter years. This means that, both the use of fertilizer and irrigation gradually increased over time. It seems that in the early years, since the prices of energy increased sharply relative to other agricultural input prices, farmers tended to use more fertilizer than irrigation due to high irrigation costs.

Table 6.17: Estimated Cross-Elasticities of Input Demand for the Non-homothetic Structure with Technical Change, 1973 – 1995

Year	N-L	N-F	N-I	L-F	L-I	F-I
1973	-0.5517	0.0000	-0.0015	-0.0002	-0.0001	0.7677
1974	-1.2588	0.0001	-0.0021	-0.0002	-0.0001	0.5166
1975	-0.9052	-0.0001	-0.0017	-0.0001	-0.0001	1.7425
1976	-0.3350	0.0001	-0.0013	-0.0002	-0.0001	0.7435
1977	-0.0094	0.0003	-0.0008	-0.0002	-0.0001	0.4686
1978	0.0539	0.0008	-0.0009	-0.0002	-0.0002	0.3300
1979	0.0956	0.0008	-0.0007	-0.0002	-0.0002	0.3123
1980	0.0979	0.0006	-0.0008	-0.0003	-0.0002	0.4185
1981	0.0967	0.0017	-0.0007	-0.0001	-0.0002	0.2265
1982	0.0760	0.0015	-0.0007	-0.0001	-0.0001	0.3331
1983	0.0292	0.0017	-0.0007	-0.0001	0.0000	0.3810
1984	-0.0055	0.0024	-0.0009	0.0001	0.0000	0.2829
1985	-0.2100	0.0038	-0.0016	0.0005	0.0000	0.1949
1986	-0.1922	0.0011	-0.0017	-0.0001	-0.0001	0.4214
1987	-0.2002	0.0016	-0.0017	0.0000	-0.0001	0.3368
1988	-0.1196	0.0021	-0.0014	0.0001	0.0000	0.3014
1989	-0.2242	0.0041	-0.0016	0.0005	0.0000	0.1984
1990	-0.1769	0.0048	-0.0015	0.0007	0.0000	0.1598
1991	-0.2100	0.0044	-0.0015	0.0006	0.0001	0.1982
1992	-0.2838	0.0045	-0.0017	0.0006	0.0001	0.2043
1993	-0.3233	0.0037	-0.0019	0.0004	0.0001	0.2383
1994	-0.3661	0.0036	-0.0020	0.0004	0.0001	0.2431
1995	-0.3625	0.0035	-0.0020	0.0004	0.0001	0.2536

Table 6.18: Estimated Cross-Elasticities of Input Demand for the Non-homothetic Structure with Technical Change, 1973 – 1995

Year	L – N	F – N	I – N	F – L	I – L	I – F
1973	-0.1475	0.0004	-0.0408	-0.0132	-0.0119	1.0374
1974	-0.2773	0.0009	-0.0491	-0.0102	-0.0113	0.8517
1975	-0.2145	-0.0042	-0.0460	-0.0162	-0.0119	1.6163
1976	-0.0985	0.0013	-0.0372	-0.0134	-0.0122	1.0076
1977	-0.0035	0.0054	-0.0299	-0.0124	-0.0136	0.8059
1978	0.0232	0.0120	-0.0231	-0.0078	-0.0110	0.5590
1979	0.0459	0.0132	-0.0204	-0.0079	-0.0115	0.5369
1980	0.0471	0.0114	-0.0192	-0.0097	-0.0103	0.5913
1981	0.0522	0.0209	-0.0145	-0.0020	-0.0088	0.3982
1982	0.0385	0.0190	-0.0115	-0.0032	-0.0041	0.4283
1983	0.0136	0.0197	-0.0091	-0.0015	0.0010	0.4157
1984	-0.0024	0.0232	-0.0111	0.0027	0.0004	0.3655
1985	-0.0750	0.0269	-0.0187	0.0091	0.0000	0.3159
1986	-0.0657	0.0131	-0.0230	-0.0038	-0.0030	0.5015
1987	-0.0688	0.0161	-0.0223	-0.0010	-0.0026	0.4424
1988	-0.0449	0.0199	-0.0174	0.0016	-0.0006	0.3943
1989	-0.0800	0.0279	-0.0173	0.0100	0.0015	0.3092
1990	-0.0660	0.0313	-0.0173	0.0128	0.0000	0.2853
1991	-0.0765	0.0294	-0.0152	0.0112	0.0029	0.3001
1992	-0.0981	0.0291	-0.0161	0.0115	0.0039	0.3008
1993	-0.1075	0.0254	-0.0180	0.0084	0.0034	0.3284
1994	-0.1185	0.0247	-0.0190	0.0081	0.0033	0.3328
1995	-0.1175	0.0242	-0.0186	0.0076	0.0036	0.3378

About the rising tendency of land-fertilizer substitution, it seems that a moderate increase in cultivated land might have caused the increasing consumption of fertilizer to a great extent in Bangladesh agriculture to enhance agriculture production.

Of all the positive cross-price elasticities, land-fertilizer cross elasticity gradually increased over time while fertilizer-irrigation cross price elasticity slowed down over the latter period.

Of all the positive cross-price elasticities, the highest fertilizer-irrigation cross price elasticity is common among the three structures of the model and it gradually declined over the latter years. It seems that in the early years, the demand for fertilizer was more responsive to the changes in the irrigation prices than that to other input prices but over time this responsiveness tended to decline.

6.4 Summary

The main empirical results of this chapter are stated below:

1. Both substitutability and complementarity relationships exist in Bangladesh agriculture.
2. Both the land-fertilizer and fertilizer-irrigation input pairs displayed substitution relationship in three structures of the translog model. The complementary relationship of land-irrigation and labour-irrigation were also common in these three structures.

3. In studying factor substitution in Bangladesh agriculture, the translog specification was found to be a better specification than the restrictive Leontief, Cobb-Dougals (CD) and constant elasticity of substitution (CES) functions.

4. Most of the own price elasticities of demand for farm inputs were found to be less than one which indicated prevalence of inelastic demand for farm inputs. The highest price elasticity of demand for fertilizer was common in the three structures of the model.

5. There was some evidence of augmented technical change in Bangladesh agriculture. There was an evidence of land and labour saving and presence of fertilizer and irrigation using technical changes.

6. The extent of non-homotheticity was found to be quite strong. Under the both non-homothetic structures (with and without technical change), all the estimated output coefficients were significantly different from zero which implied presence of scale effect and effect of size of the farms.

7. Considerable changes occurred in input relationship in Bangladesh agriculture over time. Differences exist in sign and magnitude of the values of AES and various cross price elasticities.

8. In both the homothetic and non-homothetic structures, positive cross price elasticity of demand for irrigation-fertilizer and fertilizer-irrigation displayed a declining tendency while the positive cross price elasticity of demand for fertilizer-land and land-fertilizer showed an increasing tendency over the latter period from 1973 to 1995.

9. Statistically, the translog model performed fairly well under a multi input production framework.

10. Among the three structures of the translog model, the non-homothetic structure with technical change comprehensively explained the condition of Bangladesh agriculture.

CHAPTER 7

A STUDY OF PRODUCTIVITY IN BANGLADESH AGRICULTURE

In this chapter, an attempt is made to see whether productivity growth has increased due to the adoption of irrigation-fertilizer technology in the Bangladesh agriculture sector. In productivity studies, different researchers used different productivity indexes and different indexing procedures. In recent years, both the concepts of total factor productivity and flexible weight indexing procedures have been used in the productivity studies. Following the recent developments in the study of productivity measurement, Hossain (1973), Brown (1978), Islam (1982), Griliches and Lichtenberg (1984), Wolff (1985), Gray (1987) and Ali (1991) used the total factor productivity indexes in their respective fields. In case of choosing the flexible weight indexing procedures Berndt and Wood (1975), Griffin (1981), Islam (1982), Norsworthy and Malmquist (1983), Aw and Roberts (1985), Wolff (1985), Kuroda (1987) and Ali (1991) applied the Divisia indexing procedure in several types of production structure related studies. In case of agricultural productivity, the works of Lee and Chen (1978), Brown (1978), Lawrence and McKay (1980), Islam (1982), Whittaker (1983), Ball (1985), Bottomley *et al.* (1990) and Ali (1991) are noteworthy for adopting the Divisia indexing method.

In the Bangladesh agricultural sector, the simultaneous use of these two concepts is rare in the recent productivity studies. Using the Divisia indexing procedure, the total factor productivity indexes are employed in this study as an improved measure of productivity growth. This study also includes the issue of benefits from productivity gain.

This chapter is divided into seven sections. In the first section, the changing trend of growth rates in Bangladesh agriculture is briefly discussed. The basic concepts of partial factor productivity and total factor productivity are elaborated in the second section. The third section contains the theory of productivity measurement, while in the fourth section some selected works on productivity studies are reviewed. The main empirical estimates of total factor productivity for the Bangladesh agriculture sector are presented and analyzed in the fifth section of this chapter. In the sixth section, the distribution of productivity gains is examined. Finally, the results are summarized in the seventh section.

7.1 Changing Growth Rates in Bangladesh Agriculture

In Bangladesh agriculture, moderate growth rates in food grain production was found from the early years of the post-independence period and this trend continued with the exception of some crops. During the post-independence period, agricultural production suffered mostly due to readjustment, reorganization and rehabilitation problems. In the mid-sixties, the seed-water-fertilizer technology was introduced but these technological transformations failed to show away satisfactory growth rates. The physical factors also constitute constraints to the potential growth in increasing agricultural productivity. The flat land, the seasonal flow of water of the river network and the monsoon rains create problems in raising agricultural productivity (Hossain, 1991).

In the mid seventies, the average rate of growth of food grain output was about 3 percent while in the eighties it declined to about 2.2 percent. This happened due to significant growth of production in *boro* rice and wheat while the *aman* crop showed a very moderate upward trend and *aus* production exhibited a declining trend (GOB, 1990).

During the first three years of third five year plan (TFYP), the growth rate of agriculture sector was 4.1 percent in 1985-86 and this happened due to a 70 percent increase of jute production. In 1986-87 the growth rate came down to 3.1 percent and in 1987-88, the growth rate fell drastically to 0.05 percent due to floods (Hossain, 1991). In Bangladesh, as a dominant production activity sector, the relative contribution of the agriculture sector to the Gross Domestic Product (GDP) has declined over time. In 1972-73, the contribution of this sector to the GDP was 50 percent and in 1991-92 it declined to 37. Since the contribution of secondary sector increased, the direct effect of this situation created the relatively slower growth rate of agriculture and in the 20-year period from 1972-73 to 1991-92, the growth rate of agriculture was found to be 2.16 percent per annum (BBS, 1993).

7.2 Concepts of Partial and Total Factor Productivity

In physical terms, productivity can be defined as the relationship of output to the related inputs. When the growth of output exceeds the rate of growth of inputs, productivity increases and in the reverse situation, productivity declines. In the study of productivity, two types of productivity measures are basically used of which the first is partial factor productivity (PFP) and the other is total factor productivity (TFP). The ratio of output to a particular input is known as partial factor productivity such as the partial productivity of land, partial productivity of labour, partial productivity of fertilizer. On the contrary, the ratio of output to all productive inputs taken together is known as total factor productivity. In practice, it is not possible to include all the inputs in the production process. So, the ratio of the single aggregate output to the single aggregate set of the traditional inputs are used to measure total factor productivity. The application of TFP in relation to the PFP approach was discussed by Hossain (1973:3) in the following words:

> One can measure as many productivity indices as there are factors of production but since land is the most scarce factor of production in Bangladesh we shall mainly be concerned here with the productivity of land, and the reasons of its variation among different size groups of farms. We shall also try to derive indices of total productivity by size-groups by taking into account the marginal contribution of traditional factors land and labour and the growth augmenting modern factors – fertilizer and irrigation.

The rationale for adopting the TFP approach for study of the Bangladesh agriculture sector was clarified by Hossain (1973:29) thus:

> We also noted that the higher productivity of land in smaller farms was associated with the higher application of other factors per unit of land. And it can be argued that while from the societies point of view land is the most scarce factor and land productivity should be maximized, it may not be so in the case of large farms who have abundant land relative to other factors of production. So in order to decide which size-group is the most efficient in using the available resources one should look at the index of total productivity rather than productivity of a particular factor.

In calculating productivity growth, and in choosing the TFP measure, Gray (1987:1001) made the following comment:

To reduce the impact of strong cyclical fluctuations in productivity, average TFP growth is calculated for periods covering several years, chosen to match the cycle of productivity fluctuations from peak to peak.

Though the partial factor productivity (PFP) measure is widely used method, it faces several limitations. The PFP measure consists of a particular input and it is unable to represent the extent of productivity growth. The partial factor measure is widely used as a precise method but in recent years the TFP approach has gained popularity due to its ability to consider all productive inputs. Thus, TFP is regarded as a realistic measure and to obtain a significant result of productivity growth, the TFP measure is used in this study.

7.3 Theory of Productivity Measurement

Basically, the index of productivity can be defined as ratio of indexes of output and inputs. Thus to construct the indexes of output and inputs, generally two types of indexing procedures are used. Among these procedures, the first is the fixed-weight approach, that is, the Laspeyres and Paasche indexes and the other is flexible-weight approach of which the Divisia index and its discrete Tornqvist approximation are most popular in economic studies. Now the basic concepts of these two indexing procedures are discussed below.

The Laspeyres or the Fixed-Weight Approach

The Laspeyres indexing procedure is widely used for general purpose in most of the official statistics. The Laspeyres quantity index can be constructed using the following formula,

$$Q_t = \frac{\sum P_0 Q_t}{\sum P_0 Q_0} \tag{7.1}$$

where Q_t is the quantity index in period t, Q's and P's are item quantities and prices, and 0 and t indicate the base year and current year, respectively. Following equation (7.1), the quantity index can be written as

$$Q_t = \frac{\sum P_0 Q_0 (Q_t / Q_0)}{\sum P_0 Q_0} \tag{7.2}$$

From these above stated equation, it is observed that the construction of the index requires only quantity data for subsequent years while price is considerd fixed at the base period level. Due to its simplicity, the Laspeyres index is mostly used by government statistical organisations.

Though the Laspeyres index are widely used, it has several shortcomings. The Laspeyres quantity index considers prices fixed at the base period level and it is able to compare the base period value of current period quantities with base period value of the base period quantities. It indicates a linear production function, showing perfect substitution between all factors. The Laspeyres index is sensitive to the choice of a base period. Like other countries, Bangladesh has also experienced wide ranging fluctuations in agricultural production and prices. Besides this, circumstances like floods, cyclones, droughts can affect agricultural production as well as it as its prices. In this context, consideration of only a particular year as the fixed base of the index could be unsatisfactory.

The Divisia or Flexible Weight Approach

To overcome the above stated problems, the Divisia indexing procedure were proposed by Divisia (1926). It involves a flexible weight method. In continous version, the Divisia index can be presented as

$$Q_t/Q_0 = \exp\left\{\int [W_i(t)(\dot{q}_i(t)/q_i(t))]\right\} \tag{7.3}$$

The W_{it} implies the share of the i-th factor in total cost or the share of the i-th output in total value and a dot (.) over the variable indicates the logarithmic derivative of that variable. Equation (7.3) shows the continuous version of the Divisia index. But its empirical implementation requires a discrete approximation and the Tornqvist approximation is considered appropriate for the translog function. This widely used approximation was proposed by Tornqvist (1936). Following equation (7.3), the Tornqvist approximation to the Divisia quantity index can be written as

$$1nQ_t - 1nQ_{t-1} = \sum \overline{W}_{it}(1nq_{it} - 1nq_{i,t-1}) \tag{7.4}$$

where Q denotes quantity and i refers to sub components.

In case of both the price and quantity indexes, the weights (w) are the same. A given weight implies the arithmetic mean of the shares in two adjacent periods and the weight can be presented as

$$\overline{W}_{it} = \frac{1}{2}\left(w_{it} + w_{i,t-1}\right) \qquad (7.5)$$

The weights in (7.5) are flexible over time. The Tornqvist approximation is used in this study to estimate productivity in Bangladesh agriculture.

7.4 A Review of Productivity Studies in Agriculture

In recent years, both the field-level data and aggregate data have been used to study productivity in Bangladesh agriculture. The findings of these studies varied due to adoption of different procedures. This review of selected productivity studies are divided into two sections. The first section contains a review of some of the literature on agricultural productivity in Bangladesh. The second section contains a survey of studies which used the flexible weight indexing procedure.

Agricultural Productivity in Bangladesh

In Bangladesh, several studies have been done in the field of agricultural productivity. Though most of these studies are not conceptually or methodologically same as our study, a short review of these studies is made to get a picture of productivity growth in Bangladesh agriculture.

An early study of both partial factor productivity (PFP) and total factor productivity (TFP) in Bangladesh agriculture was conducted by Hossain (1973). This study is based on 95 farms of Phulpur in the Mymensingh district. In this study, productivity of land and labour was found to be highest for the 2.5 to 5.0 acre size group. On the other hand, this study indicated the relatively low productivity of land and labour in large farms. By considering the TFP in agriculture it was found that the 2.5 to 5.0 acre size group were the most efficient. In this study, there were indications that by increasing the percentage of land for the small farms, it might be possible to increase productivity and growth of agriculture. This study also suggested that in the agriculture sector some kind of selective mechanization could lead to an increase in agricultural output and employment.

Hossain (1977) studied productivity of land by adopting a partial factor productivity approach. Using farm level data of the Bangladesh agriculture sector, he classified the farms for calculation of land productivity. He found the difference in land productivity between owner I (land up to 6.5 acres) and owner II (land above 6.5 acres) and examined the inverse relationship between farm size and productivity. In this study, productivity of land was found higher for small owner-cultivators than the large owners. This result was similar to the result he obtained in his earlier work (Hossain,1973).

Mandal (1980) studied productivity with respect to farm size and tenancy using the data of intensive farm survey. In this study, the inverse relationship between farms size and productivity which is found in an earlier study (Hossain, 1977) was not sustained. To control the tenure effect, he classified the owner-farms into three size groups. This study indicated that productivity per acre could increase up to a certain level, then it declined as farm size increased further. Medium farms appeared as more productive than both the small and large farms.

Abedin and Bose (1988) worked on the controversial issue of farm size and productivity relationship. The earlier studies did not give importance on the contribution of factors which created the differences among small, medium and large farms. In this study, they studied the relationship between farm size and productivity using the decomposition analysis. Using farm level data on irrigated HYV *Aman* rice in Thakurgaon, this study showed positive relationship between farm size and productivity. In case of input use, the medium and large farms used more modern inputs, specially fertilizer, than the small farms. This study also looked into the factors like intensive use of family labour, cropping pattern and cropping intensity and technological differences.

Hossain (1988) studied the effect of new technology on productivity of land and labour. By using farm level cross section data for 1982, he found that the sum of the output elasticities, that is, the factor shares of land and labour, is less than one for modern variety *boro* while it is greater than one for other varieties of rice. This study indicated that due to adoption of modern technology, a farmer might get increasing net returns from the land. But in case of increasing productivity of labour, the effect of modern technology was small. In the use of labour, inefficiency was found and it happened due to low opportunity cost of family labour.

Matin (1989) studied productivity of rice production using district level data for the period 1976-77 to1984-85. The effect of farm size and input use on the yield of rice was also analyzed in this study. This study showed the existence of positive size-productivity relationship. But an weakening of inverse relationship of size-productivity was also observed in this study and it happened due to appearance of technological changes in agricultural productivity. In case of the relationship between input use and size of holdings, it was observed that farm size, agricultural labour, concentration of cultivation, and use of pesticides had significant positive effect on the yield of rice.

Hossain (1990) studied the long-term growth performances of major agricultural crops and measured the differences in agricultural productivity among different regions of Bangladesh. This study was based on the data from 1949-50 to 1987-88. In this study, a poor performance in production of individual crops was observed which indicated an unsatisfactory growth in total crop output. This study also indicated the importance fertilizer and irrigation for increasing agricultural productivity. By considering the relative contribution of component elements for the crops it was observed that area expansion had the largest contribution to the change in output of *boro* while increase in output of *aus* and *aman*, the increasing productivity was found to have the largest contributor.

Hossain (1991) studied the performance of the crop sector of Bangladesh agriculture from 1967-70 to 1981-84 (period I) and from 1967-70 to 1985-88 (period II). This study also analyzed the relative contributions of different productivity components to the crop sector output growth. It is observed that during the period from 1967-70 to 1985-88, total crop output in Bangladesh agriculture increased by 1.53 percent per annum while the population growth rate was 2.70 percent per annum which indicated an unsatisfactory growth rate in the per capita output of the crop sector. This study examined the impact of seed-water-fertilizer technology on crops and observed that this program had no effect on the productivity of individual crops but an exception is found for rice, wheat, jute, rape and mustard and potatoes. As compared to period I, the magnitudes of positive productivity effect on the output growth of *boro* rice, wheat, jute, potatoes and tobacco were small and the intensities of negative productivity effect on sugarcane, garlic and groundnut were large in period II. The average rates of increase in the crop sector output were 0.53 and 0.93 percent per annum in periods I and II respectively.

Agricultural Productivity: The Flexible Weight Approach

In recent years, the flexible weight indexing method was used to study agricultural productivity. These include the works of Lee and Chen (1978), Brown (1978), Lawrence and McKay (1980), Islam (1982), Whittaker (1983), Ball (1985), Bottomley *et. al*. (1990) and Ali (1991). These are reviewed below.

Lee and Chen (1978) studied both TFP and PFP approaches for productivity growth in the Taiwan agriculture. In this study, he applied the Tornqvist approximation to the Divisia index but its computational procedure was different from the method which is used in this study.

Brown (1978) examined the productivity changes in U.S. agriculture using the TFP approach. In this study, the Tornqvist and Star-Hall implementations of the Divisia index were applied and the results compared. By using the Tornqvist index, an annual rate of productivity growth of 1.15 percent was found during the period from 1947 to 1975. When the period was divided into two parts, a growth rate of productivity of 1.98 percent for 1947 to 1960 and 0.39 percent for 1960 to 1974 were found for the U.S. agriculture.

Lawrence and McKay (1980) conducted a study of productivity in the Australian sheep industry. Both TFP and PFP approaches and the Divisia indexing procedures were applied in the study. Estimation of the terms of trade and returns to cost was also done. He obtained an annual rate of TFP growth of 2.9 percent during the period from 1952-53 to1976-77.

In his doctoral dissertation, Islam (1982) studied productivity growth in Canadian agriculture. He also separately examined the productivity change for Western Canada. In this study, both the TFP and PFP approaches were applied covering the period from 1961 to 1978. He used the Tornqvist and the Star-Hall approximations of the Divisia index to obtain productivity growth rates. In this study, based on manhours data, TFP increased by 1.83 percent per year between 1961 and 1978. Declining growth rate in Canada was found in the latter period while the TFP growth rates in Western Canada was higher in the same period. The estimation of terms of trade and returns to cost ratio was also done in this study.

Whittaker (1983) conducted a study of productivity change in UK agriculture for the period 1964 to 1979. The partial labour productivity and the TFP indexes were employed in this study. The Tornqvist method of Divisia indexing procedure was applied to measure the TFP indexes as an improvement over the TFP index.

Ball (1985) updated Brown's (1978) work in his study of agricultural productivity in US agriculture. He used the TFP indexes by using time series data for the period from 1948 to 1979. To measure productivity, Tornqvist-Theil implementation of the Divisia indexing procedure was used. By considering the TFP, an average annual rate of 1.75 percent was obtained in this study.

Bottomley *et al.* (1990) studied the productivity change in UK agriculture for the period 1962 to 1987. In this study, they employed the Tornqvist-Theil approximation to the Divisia index to estimate TFP. In all, data of 5 outputs and 9 inputs were considered in this study.

In his doctoral thesis, Ali (1991) studied productivity change in UK agriculture for the period 1967 to 1987. PFP and TFP estimates were obtained in this study. To construct the output and input indexes, the Tornqvist-Theil approximation to the Divisia index was applied. The estimates of terms of trade and the returns to costs ratio were also obtained in this study.

7.5 Estimates of Total Factor Productivity

Total factor productivity is defined as the ratio of the quantity indexes of output to quantity indexes of all inputs. So in order to derive an index of total factor productivity, it is necessary to construct quantity indexes of total output and all inputs. In our study, the quantity index of aggregate output is constructed by combining all crops together. Indexes of aggregate output included a total of twenty five items of crops. The data of agricultural output includes cereals, cash crops, pulses, oilseeds, vegetable, fruits and spices. Among the cereals, rice (medium) and wheat and among the cash crops jute and sugarcane are used. In case of pluses, *masur*, gram, *mashkalai* and *moong* while in the spices group, chillies, onion and garlic are taken in this study. Among the oilseeds group, rape and mustard, *til*, linseed and coconut are included while among the vegetables, brinjal, tomato, cauliflower and radish are considered. In case of fruits, banana, mango, jack fruit and pineapple and among the tuber crops only potato is chosen for this study. Besides this, tea is also included. The time series data on price and quantities of output are entirely obtained from various issues of *Statistical Yearbook of Bangladesh, Yearbook of Agricultural Statistics* and *Monthly Statistical Bulletins* which are the publications of Bangladesh Bureau of Statistics (BBS). The Tornqvist approximation of the Divisia index is used to construct the output and input indexes. This is done by using the econometric software *SHAZAM*.

The Divisia quantity indexes of all agricultural output are presented in Table 7.1. The year 1973 is considered as the base year. The index of agricultural output was 1.146 in 1974 and it increased steadily and stood at 1.869 in 1995. During this period, the annual growth rate of output index was 2.83 percent.

Divisia quantity indexes of inputs are reported in Table 7.2. By combining all the inputs (land, labour, fertilizer and irrigation), the all input index is constructed here. The index of all inputs gradually increased over time and its annual growth rate was 1.12 percent during the study period.

To see whether the growth rates has accelerated or not by the adoption of modern technology and by following Pesek (1961), Griffin (1974), Veeman (1975) and Islam (1978) the following trend equation (7.6) has been fitted for the period (1973 to 1995) for computing the growth rates.

$$L_n\, g(t) = a+bt+u \qquad (7.6)$$

where g(t) is the variable for which the rate of growth is estimated and t and u stand for time and stochastic error respectively. Here the compound growth rate was obtained by the antilog of the estimated coefficient on time minus one. Here L_n implies the natural logarithm of the variable.

Table 7.1: Divisia Quantity Index of Agricultural Output in Bangladesh, 1973-1995 (1973 = 1.000)

Year	All Output
1973	1.000
1974	1.146
1975	1.091
1976	1.377
1977	1.299
1978	1.382
1979	1.391
1980	1.384
1981	1.516
1982	1.409
1983	1.564
1984	1.636
1985	1.651
1986	1.714
1987	1.736
1988	1.778
1989	1.766
1990	1.971
1991	1.947
1992	1.970
1993	1.991
1994	1.916
1995	1.869
Annual Growth Rates (in percent) (1973-1995)	2.83

Table 7.2: Divisia Quantity Index of Agricultural Inputs in Bangladesh, 1973-1995 (1973 = 1.000)

Year	All Input
1973	1.000
1974	1.029
1975	1.014
1976	1.024
1977	1.024
1978	1.045
1979	1.073
1980	1.078
1981	1.061
1982	1.105
1983	1.123
1984	1.124
1985	1.139
1986	1.173
1987	1.167
1988	1.167
1989	1.188
1990	1.212
1991	1.226
1992	1.236
1993	1.243
1994	1.250
1995	1.264
Annual Growth Rates (in percent) (1973-1995)	1.12

Total factor productivity is the ratio of the index of output and the index of all inputs. Table 7.3 shows total factor productivity indexes for Bangladesh agriculture. Though the total factor productivity index fluctuated, an overall rising trend was observed during the sample period. In 1974, the TFP index was 1.113 and it increased to1.479 in 1995. During this whole period, TFP index increased at an annual rate of 1.69 percent.

The graphical presentation of output, input and TFP indexes are shown in Figure 7.1. From this figure it is observed that during the study period an overall increase in productivity is found and it reached peak level in 1990 but fluctuated in the latter years of the sample period. The aggregate input index increased very slowly while the aggregate output index grew at a faster rate. The movements of output and productivity were nearly identical.

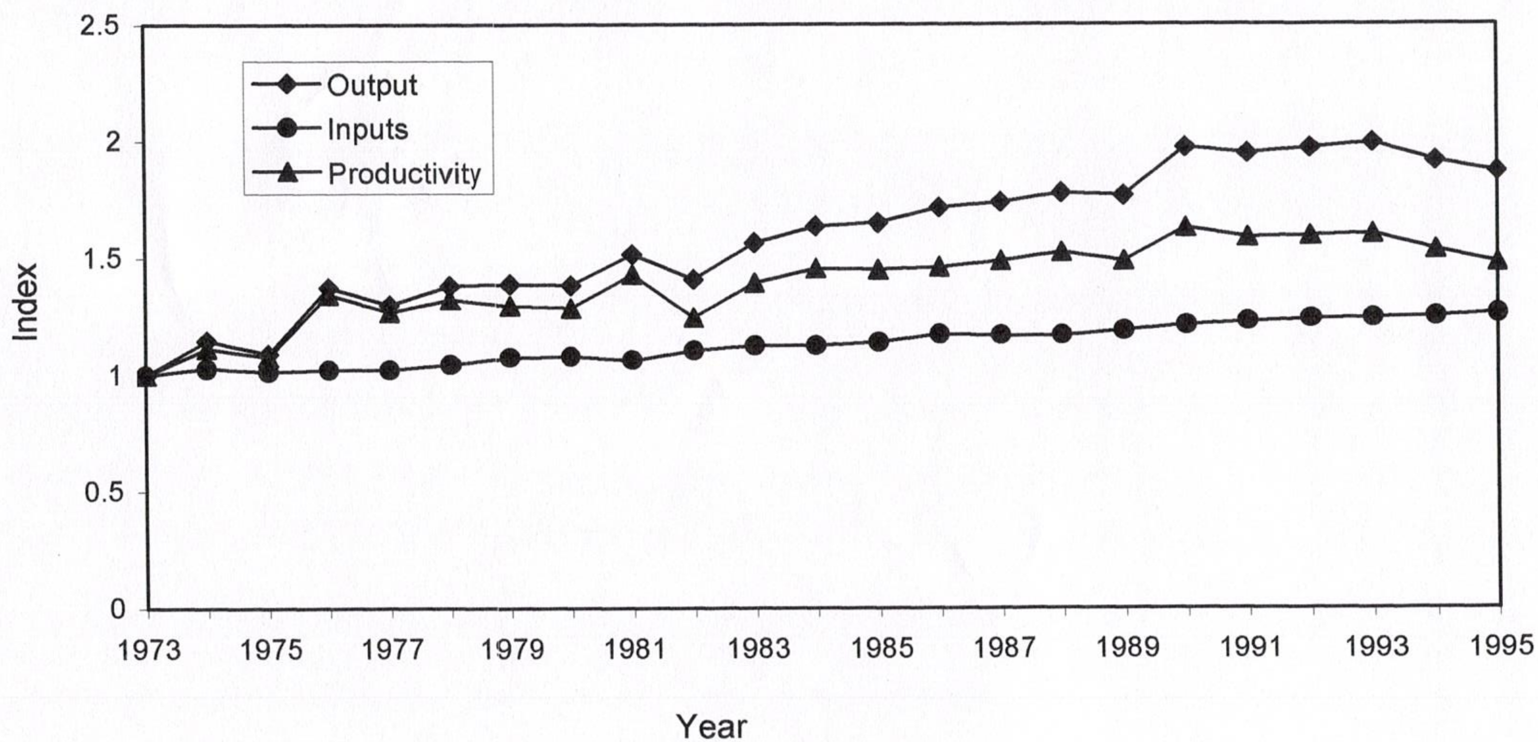
7.6 Distribution of Productivity Gains

In the study of productivity, it would be reasonable to explore the benifits of productivity growth by considering the changes in farmers' terms of trade and returns to costs. This will enable us to know how much the farmers benefited from the distributional impacts of productivity changes in Bangladesh agriculture. In earlier similar works, Lawrence and McKay (1980) studied the farmers economic position based on income from farm sources. Following Lawrence and McKay (1980), Islam (1982) studied the distribution of productivity gains for the Canadian agriculture. Ali (1991) examined this issue for the UK Agriculture. All these studies adopted the concepts of terms of trade and returns to costs ratio.

Table 7.3: Indexes of Agricultural Output, Inputs and Total Factor Productivity in Bangladesh, 1973-1995 (1973=1.000)

Year	Output	Inputs	Productivity
1973	1.000	1.000	1.000
1974	1.146	1.029	1.113
1975	1.091	1.014	1.076
1976	1.377	1.024	1.345
1977	1.299	1.024	1.268
1978	1.382	1.045	1.322
1979	1.391	1.073	1.296
1980	1.384	1.078	1.284
1981	1.516	1.061	1.429
1982	1.409	1.105	1.274
1983	1.564	1.123	1.393
1984	1.636	1.124	1.455
1985	1.651	1.139	1.449
1986	1.714	1.173	1.461
1987	1.736	1.167	1.486
1988	1.778	1.167	1.522
1989	1.766	1.188	1.486
1990	1.971	1.212	1.626
1991	1.947	1.226	1.587
1992	1.970	1.236	1.593
1993	1.991	1.243	1.601
1994	1.916	1.250	1.533
1995	1.869	1.264	1.479
Annual Growth Rates (in percent)			
(1973-95)	2.83	1.12	1.69

Figure 7.1: Indexes of Agricultural output, Inputs and Total Factor Productivity in Bangladesh, 1973-1995 (1973 = 1.000)



Terms of trade is defined as the ratio of the index of output price to the index of inputs prices while the returns to cost is defined as the ratio of the index of value of output and value of inputs. In order to obtain the index of terms of trade, it is necessary to construct the price indexes of output and inputs. Following Lawrence and McKay (1980) and Islam (1982), the Divisia indexing method is used to construct all these indexes.

Now the price index of aggregate output and price index of aggregate input and terms of trade are presented in columns 1,2 and 3 respectively of Table 7.4. From 1973 to 1995, the terms of trade declined over time. In the early years of the sample period, the terms of trade was improving because during this period output prices was higher than input prices. But from 1976, the terms of trade tended to deteriorate and this situation continued over the latter period. It happened due to increases of input prices. During the sample period (1973-95), the terms of trade had a negative annual growth rate of –1.19 percent.

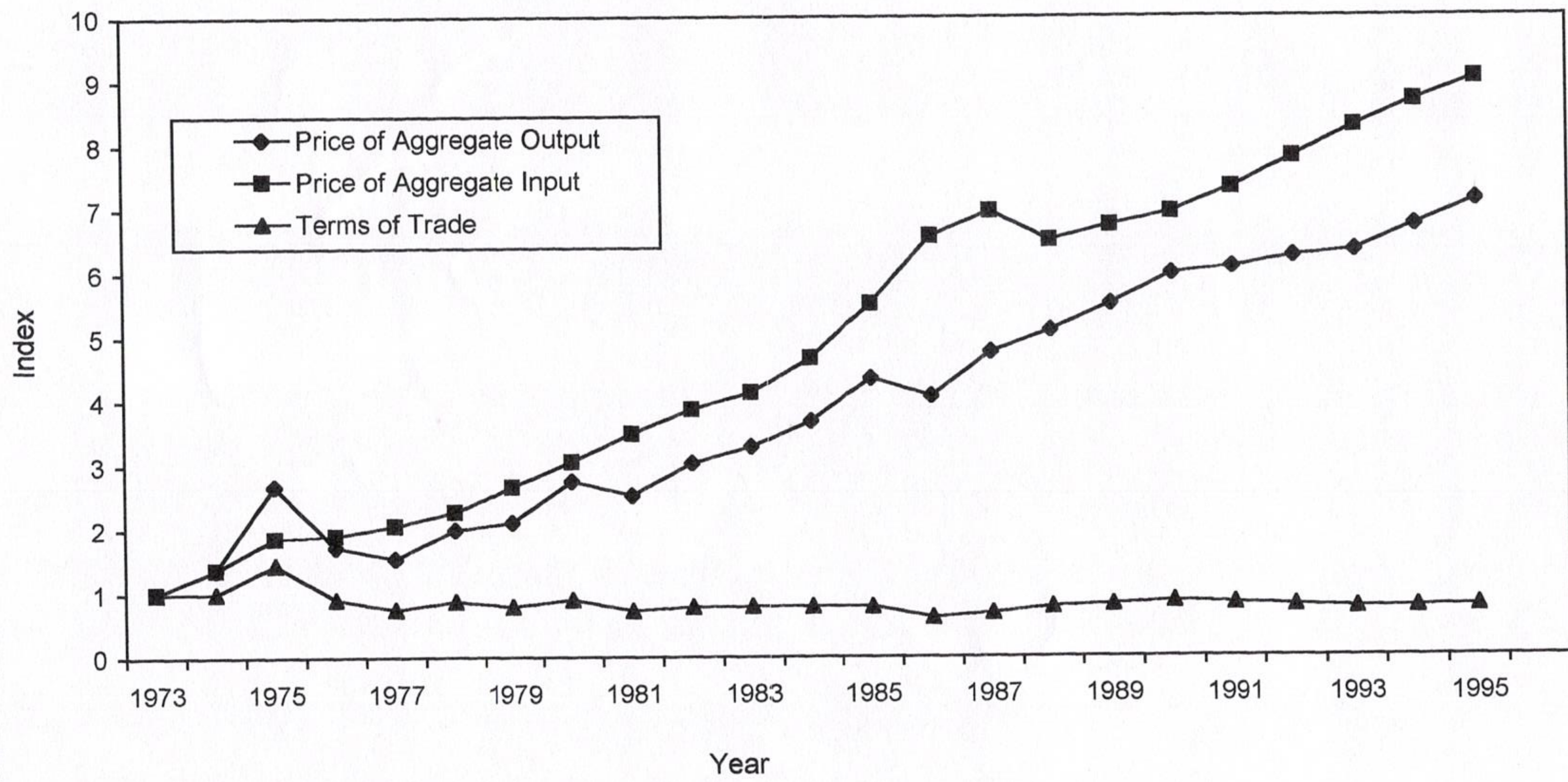
A graphical representation of the aggregate output and inputs, and terms of trade is given in Figure 7.2. It can be seen that the index of terms of trade rose in 1975 but from 1976 it tended to fall and it continued over the latter period. During the period from 1976 to 1995, the price indexes of inputs remained always high as compared to the price index of output.

But by only considering the changes in the growth rates of the terms of trade, the farmers' economic position can not be fully determined. To know farmers' economic position, both the growth rate of terms of trade and the growth rate of productivity have to be examined. Improved welfare position of the farmers can be achieved if growth of productivity is higher than the decline in the terms of trade.

Table 7.4: Price Indexes of Aggregate Output and Aggregate Input, and Terms of Trade in Bangladesh, 1973-1995 (1973=1.000)

Year	Price Index of Aggregate Output	Price Index of Aggregate Input	Terms of Trade
1973	1.000	1.000	1.000
1974	1.366	1.371	0.996
1975	2.681	1.864	1.438
1976	1.721	1.900	0.905
1977	1.540	2.062	0.746
1978	1.992	2.270	0.877
1979	2.106	2.657	0.792
1980	2.751	3.052	0.901
1981	2.525	3.495	0.722
1982	3.030	3.871	0.782
1983	3.286	4.135	0.794
1984	3.685	4.674	0.788
1985	4.354	5.523	0.788
1986	4.076	6.572	0.620
1987	4.762	6.963	0.683
1988	5.101	6.509	0.783
1989	5.510	6.735	0.818
1990	5.984	6.940	0.862
1991	6.082	7.320	0.830
1992	6.251	7.800	0.801
1993	6.345	8.284	0.765
1994	6.739	8.679	0.776
1995	7.124	9.029	0.789
Annual Growth Rates (in percent) (1973-95)	8.42	9.74	-1.19

Figure 7.2: Price Indexes of Aggregate Output and Aggregate Input, and Terms of Trade in Bangladesh, 1973-1995 (1973=1.000)



On the other hand, the worsening welfare position of the farmers continues if the declining term of trade is not fully offset by rises in the productivity. As given by Lawrence and McKay (1980), the relationship between returns to costs ratio, terms of trade and productivity can be presented as:

$$\begin{bmatrix}\text{Growth rate of} \\ \text{Returns to costs}\end{bmatrix} = \begin{bmatrix}\text{Growth rate} \\ \text{of productivity}\end{bmatrix} + \begin{bmatrix}\text{Growth rate of} \\ \text{Terms of trade}\end{bmatrix} \qquad (7.7)$$

Since the growth rate of productivity and the growth rate of terms of trade is obtained here, it is easy to obtain the growth rate of returns to cost. Corresponding to equation (7.7), the derived growth rate of the returns to costs is +.50 for the sample period. Since the negative growth rate of terms of trade is obtained during the sample period, here the growth rate of returns to costs is found positive and it occurs due to the higher positive contribution of productivity growth rates. Though the annual growth rate of returns to cost was very low, its positive growth rates implied that the farmers' welfare position in Bangladesh slightly improved during the sample period.

7.7 Summary

The main empirical findings of the this chapter are presented below:

(1) In Bangladesh agriculture, there has been productivity growth over time. Total factor productivity (TFP) increased at an annual growth rate of 1.69 percent during the sample period from 1973 to 1995.

(2) During the entire period, growth rate of the quantity index of output was 2.83 percent while that of quantity index of inputs was 1.12 percent. The steady increase of output helped growth of total factor productivity.

(3) In order to explore the distribution of productivity gains, terms to trade is derived for 1973-1995 period. During this period, the annual growth rate of the price index of output and price indexes of input were 8.42 percent and 9.74 respectively. The index of terms of trade decreased at an annual growth rate of –1.19 percent. Thus the terms of trade deteriorated during 1973-1995 period and went against the farmers.

(4) The concept of returns to costs ratio is defined as the ratio of the indexes of the value of output to the indexes of value of inputs. The derived growth rate of returns to costs was 0.50 percent. This gives an indication that, based on the farm income sources, farmers' welfare position slightly improved during the sample period.

CHAPTER 8

SUMMARY AND CONCLUSIONS

In this chapter, the findings of this study have been summarized. Besides, policy implications of the present study and possible extensions for further research are also given. The chapter ends with some concluding remarks.

8.1 Summary

This study examined several aspects of the Bangladesh agricultural sector. Firstly, by using the cost share equations corresponding to various modifications of the translog cost function the substitutability and complementarity relationships were studied under a multi input production framework. Secondly, by applying the total factor productivity (TFP) concepts and flexible weight Divisia indexing procedure, productivity growth rates were estimated. Thirdly, the distribution of productivity gains was also examined.

Translog Estimates of Factor Substitution

To examine the possible substitution between various inputs, the translog cost function, which is not bounded by any *a priori* restrictions, was used. By using four inputs of land, labour, fertilizer, and irrigation, three modifications of the translog cost function were applied here. These were a homothetic structure without technical change, a non-homothetic structure without technical change and a non-homothetic structure with technical change.

For estimating the parameters of the translog model, price indexes of four inputs were constructed for the period from 1973 to 1995. The price of land registered the highest increase and this was followed by the price of irrigation and the other two inputs. As compared to land and irrigation, the increases in the prices of labour and fertilizer were found to be quite moderate.

Substitutability of land-fertilizer and fertilizer-irrigation input pairs was found in all three structures of the translog model while appearance of complementarity of land-labour, land-irrigation and labour-irrigation were also common in these three structure. These types of substitutability and complementarity are consistent with the fertilizer using and irrigation using technological changes observed in Bangladesh agriculture.

A high degree of substitutability between fertilizer and irrigation was found in both homothetic and non-homothetic structures. Most of the own price elasticities of demand for inputs were found to be less than one which implied an inelastic demand for farm inputs. The highest value of price elasticity of demand was found for fertilizer and this was common in all three structures of the model.

Over time, the substitutability trend between fertilizer and irrigation changed and showed a declining tendency. This means that at the initial stage farmers used more fertilizer than irrigation and in recent years, both fertilizer and irrigation are used side by side to a significant extent. It seems that with the increase in the farmer's awareness about the benefits of irrigation farmers adopted irrigation with fertilizers in spite of the increase of the rental and sale price of irrigation equipment.

Due to the changes in input relations, it is observed that of all the positive cross-price elasticities, land-fertilizer cross price elasticity gradually increased over time and the fertilizer-irrigation cross-price elasticity significantly declined over the latter period.

The Bangladesh agriculture was found to be best characterized by the non-homothetic structure with technical change. In this structure, time coefficients of the cost share equations implied land and labour saving and the presence of fertilizer and irrigation using technical changes. In studying factor substitution, the translog specification performed fairly well under a multi input production framework and could capture the wide spectrum of changes in Bangladesh agriculture.

Estimates of Total Factor Productivity

In the study of productivity, total factor productivity (TFP) of Bangladesh was estimated by using the flexible weight Divisia indexing procedure. During the study period that is from 1973 to 1995, total factor productivity increased at an annual rate of 1.69 percent. During this period, the annual growth rate of quantity index of output was 2.83 percent while the quantity indexes of inputs grew by 1.12 percent.

Benefits of Productivity Growth

The benefits of productivity growth were also examined and it is related to the changes of farmers' terms of trade and returns to costs ratios. The sum of growth rate of productivity and growth rate of terms of trade show the growth rate of returns to costs. During the entire period, the growth rate of terms of trade was negative (–1.19) implying that the terms of trade deteriorated during the sample period. The growth rate of returns to costs was 0.50 percent which implies that farmers' welfare position slightly improved during the 1973-1995 period.

8.2 Policy Implications

It is observed from this study that there is a gradual decline in fertilizer-irrigation substitutability which implies that as modern technologies both fertilizer and irrigation appeared significantly in the agricultural sector. It seems that at the initial stage there was a lack of farmer's awareness about the benefit of modern bio technology. Though at that time the prices of inputs were kept very low as a part of induced technical change (Hossain, 1991) but over time, farmers used more fertilizer and irrigation due to gradual awareness of this benefits in spite of increasing prices of these inputs. An important policy implication of this development is that input subsidy policy should not be abruptly abandoned.

In this study, appearance of land and labour saving technical changes were observed. These changes release labour force from the agricultural sector. It is necessary that employment opportunity in the nonagricultural sector is created so that surplus labour from the agricultural sector is absorbed there.

In the study of productivity, though the total factor productivity showed an increase but the terms of trade declined over the latter period which was due to the increasing trend of the prices of inputs. Though growth of returns to costs was positive due to the positive growth of TFP if a better level of returns to cost growth is to be attained terms of trade have to be improved. It is important to give greater attention to the problem of rising input prices and measures should be taken to ensure the supply of inputs at reasonable prices.

8.3 Possible Extensions

This study is based on four inputs, that is, land, labour, fertilizer, and irrigation. If researchers want to employ more inputs like HYV (High Yielding Variety) seeds, pesticides, then it would be possible to make a wider comparison.

This study incorporated the translog single output model that is where only crops are considered as output. But there is a scope for application of the joint output model where crops and livestock or crops and fisheries can be treated as separate outputs.

In this study, the aggregate agriculture sector of Bangladesh considered to explain the nature of factor substitution and productivity change. There is a scope for further work by using the same method for different regions like Dhaka, Chittagong, Khulna and Rajshahi.

Finally, in estimating the productivity growth rates, different sub periods can be considered to take into account floods, cyclones, droughts, excessive rainfalls etc. This is likely to generate a more accurate measure of productivity change.

8.4 Conclusions

In this study of factor substitution and productivity change, the first twenty three years of the agricultural sector of Bangladesh since independence in 1971 was examined. During this period important changes occurred in the production process. The estimates of elasticities of substitution between different pairs of inputs and changes in this relationship over time presented in this study shed light on this aspect.

The estimates of productivity change and its benefits to the farmers showed significant productivity growth. At the same time, these showed that a great deal of this gain was eaten up by the adverse movement of terms of trade (the price of input grew at a much higher rate that the price of output) so that farmers' economic condition did not appreciably improve.

The first twenty three years of Bangladesh agriculture which was studied in this thesis saw our agriculture move away from the traditional mode of production to the age of modern input use. This study provides an assessment of this period. Policy makers and future researchers may find this useful.

BIBLIOGRAPHY

Abedin, J. and G.K. Bose (1988), "Farm Size and Productivity Difference: A Decomposition Analysis", *Bangladesh Development Studies*, **16**(3), 71-79.

Ahmed, I. (1977), "Technical Change and labour Utilization in Rice Cultivation: Bangladesh", *Bangladesh Development Studies*, **5** (3), 359-366.

Ahmed, K.S. and M. Rahman (1973), *Scheme for sinking of Shallow Tube-wells in Bangladesh,* Dhaka: Bangladesh Agricultural Development Corporation.

Ahmed, N.U. (1982), *Small Scale Irrigation Materials Survey,* Dhaka: USAID Research Unit.

Akridge, J.T. and T.W. Hertel (1986), "Multi-Product Cost Relationships for Retail Fertilizer Plants", *American Journal of Agricultural Economics,* **68**(4), 928-938.

Alam, M. (1982), *Bangladesh Minor Irrigation Sector:* A joint Review, Dhaka: Government of Bangladesh/World Bank.

Ali, M. (1991), "Factor Substitution and Productivity Change in United Kingdom Agriculture", unpublished Ph.D. thesis, University of Manchester, UK.

Allen, R.G.D. (1938), *Mathematical Analysis for Economists,* London: Macmillan.

Appelbaum, E. (1979), “On the Choice of Flexible Forms”, *International Economic Review,* **20**, 449-458.

Arrow,K.J , H.B Chenery , B.S Minhas and R.M Solow (1961) “Capital-Labour Substitution and Economic efficiency,” *Review of Economics and Statistics* **43**; 225-250.

Aw, B.Y. and M.J. Roberts (1985), “Role of Imports from the Newly Industrializing Countries in US Production”, *Review of Economics and Statistics* **67**(1), 108-116.

Baanante, C.A. and S. S. Sidhu (1980), “Input Substitution and Agricultural Research”, *Indian Journal of Agricultural Research,* **35**(July-September), 20-33.

BADC (1985), BADC Annual Report 1981-82, Dhaka: Bangladesh Agricultural Development Corporation (Implementation Division).

Bairam, E. (1991), “Capital-Labour Substitution in Sectors of a Less Developed Economy: The Case of Bangladesh”, *Bangladesh Development studies,* **19**(4), 87-91.

Ball, V.E. (1985), "Output, Input and Productivity measurement in U.S. Agriculture, 1948-79," *American Journal of Agricultural Economics*, Vol **67**, 475-486.

Bangladesh Bureau of statistics, *Statistical Bulletin of Bangladesh,* (Various issues), Dhaka. Monthly.

Bangladesh Bureau of statistics, *Statistical Pocket Book of Bangladesh* (Various issues), Dhaka: Statistics Division, Ministry of Planning, Government of Bangladesh.

Bangladesh Bureau of statistics, *Statistical Yearbook of Bangladesh* (Various issues), Dhaka: Ministry of Planning, Government of Bangladesh.

Bangladesh Bureau of statistics, *Yearbook of Agricultural Statistics of Bangladesh* (Various issues), Dhaka: Ministry of Planning.

BAU (1985), "Evaluation the Role of Institutions in Irrigation Programme: Some Preliminary Findings by Multidisciplinary Research Team", Mymensingh: Bangladesh Agricultural University.

BBS (1981), *Report on the Agricultural Census of Bangladesh 1977,* Dhaka: Bangladesh Bureau of Statistics.

BBS (1986), *Bangladesh Census of Agriculture and Livestock 1983-84,* Vol. **I**: Structure of Agricultural Holdings and Livestock Population, Dhaka: Bangladesh Bureau of Statistics.

BBS (1989), *Bangladesh Census of Agriculture and Livestock 1983-84,* Vol. **VI**: Analytical Report on the Census of Agriculture, Dhaka: Bangladesh Bureau of Statistics.

BBS (1993), *Twenty Years of National Accounting of Bangladesh 1972-73 to 1991-92*, Dhaka: Bangladesh Bureau of Statistics.

BBS (1994), *Bangladesh Population Census 1991*, Volume I: Analytical report, Dhaka: Bangladesh Bureau of Statistics.

BBS (1995), *Report of Labour Force Survey 1990-91*, Dhaka: Bangladesh Bureau of Statistics.

Berndt, E.R. and D.O. Wood (1975), "Technology, Prices and the Derived Demand for Energy", *Review of Economics and Statistics,* **57**(3), 259-268.

Berndt, E.R. and D.O. Wood (1979), "Engineering and Econometric Interpretations of Energy-Capital Complemetarity: Reply and Further Results", *American Economic Review,* **71**(5), 342-354.

Berndt, E.R. and D.O. Wood (1981), "Engineering and Econometric Interpretations of Energy-Capital complementarity: Reply and Further Results", *American Economic Review,* **71**(5), 1105-1110.

Berndt, E.R. and M.S. Khaled (1979), "Parametric Productivity Measurement and Choice among Flexible Functional Forms", *Journal of Political Economy,* **87**, 1220-1245.

Berndt, E.R., M.N. Darrough and W.E. Diewert (1977), "Flexible Functional Forms and Expenditure Distributions: An Application to Canadian Consumer Demand Functions", Discussion Paper No.77-10, Department of Economics, University of British Columbia, B.C.

Biggs, S.D. (1978), "Planning Rural Technologies in the Context of Social Structures and Reward Systems", *Journal of Agricultural Economics,* **29**(3), 257-271.

Binswanger, H.P. (1973), "The Measurement of Biased Efficiency Gains in US and Japanese Agriculture to Test the Induced Innovation Hypothesis", unpublished Ph.D. dissertation, North Carolina State University, Raleigh.

Bottomley, P., Ozanne, A. and Thirtle, C. (1990), "A Total Factor Productivity Index for U.K. Agriculture 1967-87" Discussion Paper No. 90/012, Dept. of Agricultural Economics and management, University of Reading.

Box, G.E.P. and D.R.Cox (1964), "An Analysis of Transformations", *Journal of the Royal Statistical Society,* Series B, **26**, 211-252.

Boyle, G. (1982), Modelling Fertilizer Demand in the Republic of Ireland: A Cost Function Approach", *Journal of Agricultural Economics,* **33**(1), 181-192.

Braeutigam, R.R., A.F. Daughety, and M.A. Turnquist (1982), "Estimation of a Hybrid Cost Function for a Railroad Frim", *Review of Economics and Statistics,* **64**(3), 394-404.

Brown, R.S. (1978), "Productivity, Returns and the Structure of Production in the US Agriculture, 1947-74", unpublished Ph.D. dissertation, University of Wisconsin, Madison.

Campbell, T.A. (1993), "KLEMS Translog Cost Estimates and Energy Elasticities," unpublished Ph.D dissertation, Florida state University, USA.

Capalbo, S.M. and M.G.S. Denny (1986), "Testing Long-run Productivity Models for the Canadian and US Agricultural Sectors", *American Journal of Agricultural Economics,* **68**(3), 615-625.

Chalfant, J.A. (1984), "Comparison of Alternative Functional Forms with Application to Agricultural Input Data", *American Journal of Agricultural Economics,* **66**(2), 216-220.

Chavas, J.P. and T.L.Cox (1990), "Non-Parametric Analysis of Productivity: The Case of US and Japanese Manufacturing", *American Economic Review,* **80**(3), 450-464.

Chotigeat, T. (1978), "An Econometric Analysis of the Translog Function and the Substitution of Capital, Fertilizer and Labour in Thai Agriculture 1953-72", unpublished Ph.D. dissertation, Southern Illinois University, Carbondale.

Christensen, L. R. (1975), "Concepts and Measurement of Agricultural Productivity", *American Journal of Agricultural Economics,* **57**, 910-915.

Christensen, L.R, D. W Jorgenson and L . J. Lau (1971), "Conjugate Duality and the Transcendental Logerithmic Production Function," *Econometrica* **39**(July), 255-256.

Christensen, L.R., D.W. Jorgenson and L.J. Lau (1973), "Transcendental Logarithmic Production Frontiers", *Review of Economics and Statistics,* **5**, 28-45.

Clark, P.K. and J.T. Haltmaier (1985), "Labour Productivity Slowdown in the United States: Evidence from Physical Output Measures", *Review of Economics and Statistics,* **67**(3), 504-508.

Considine, T.J. and T.O. Mount (1984), "Use of Linear Logit Models for Dynamic Input Demand System", *Review of Economics and Statistics,* **66**(3), 434-443.

Cowing, T. (1970), "Technical Change in Steam Electrical Generation: An Engineering Approach", unpublished Ph.D. Dissertation, University of California, Berkeley.

Darby, M.R. (1984), "US Productivity Slowdown: A Case of Statistical Myopia", *American Economic review,* **74** (3), 301-322.

Dawson, P.J. (1985), "Measuring Technical Efficiency from Production Function: Some Further Estimates", *Journal of Agricultural Economics,* **36**(1), 31-40.

Desai, M. (1976), *Applied Econometrics,* London: McGraw-Hill.

Diewert, W.E. (1971), "An Application of the Shephard's Duality Theorem: A Generalized Leontief Production Function", *Journal of Political Economy*, **79**, 481-507.

Diewert, W.E (1973), "Separability and a Generalization of the Cobb-Douglas Cost, Production, and Indirect Utility Functions", Institute for Mathematical Studies in the Social Sciences Technical report No.86, Stanford, Cal: Stanford University.

Diewert, W.E. (1974), "Applications of Duality Theory", in *Forentiers of Quantative Economics,* M.Intrillagator and David Kendric (eds.),Amsterdam: North-Holland,Vol.2,106-206.

Diewert, W.E. (1976), “Exact and Superlative Index Numbers”, *Journal of Econometrics,* **4**, 115-145.

Divisia, F. (1928), *Economique Rationalle,* Paris, 1928.

Fuss, M.A. (1977), The Demand for Energy in Canadian Manufacturing: An Example of the Estimation of Production Structures with many Inputs," *Journal of Econometrics,* **5**, 89-116.

Gallant, A.R. (1981), "On the bias in Flexible Functional Forms and an Essentially unbiased Form: The Fourier Flexible Form”, *Journal of Econometrics*, **15**, 211-245.

Gallant, A.R. (1982), "Unbiased Determination of Production Technologies," *Journal of Econometrics*, **20**, 285-323.

Gallant, A.R. (1984), “The Fourier Flexible Form”, *American Journal of Agricultural Economics*, **66**(2), 204-208.

GOB (1973), *First Five Year Plan of Bangladesh 1973-78,* Dhaka: Planning Commission, Ministry of Planning, Government of Bangladesh.

GOB (1975), *Basic Statistics of Bangladesh Agriculture,* Dhaka: Ministry of Agriculture, Government of Bangladesh.

GOB (1980), *Bangladesh Economic Survey 1979-80,* Dhaka: Ministry of Finance, Government of Bangladesh.

GOB (1985), *Third Five Year Plan 1985-90,* Dhaka: Planning Commission, Ministry of Planning, Government of Bangladesh.

GOB (1989), *Mid Term Review of the Third Five Year Plan 1985-90*, Planning Commission, Ministry of Planning, Government of Bangladesh.

GOB (1990), *Fourth Five Year Plan of Bangladesh 1990-95,* Dhaka: Planning Commission, Ministry of Planning, Government of Bangladesh.

GOB (1995), *Bangladesh Economic Survey 1993-94,* Dhaka: Ministry of Finance, Government of Bangladesh.

GOB (1998), *The Fifth Five Year Plan 1997-2002*, Dhaka: Planning Commission, Ministry of Planning, Government of Bangladesh.

Gollop, F. M. and D. W. Jorgenson," (1980), U.S Productivity Growth by Industry 1947-1973," in J. Kendrick and B vaccara (eds.),New Developments in Productivity measurements and Analysis (Chicago: University of Chicago Press,1980)

Gray, W.B. (1987), "Cost of Regulation: OSHA, EPA and the Productivity Slowdown", *American Economic Review,* **77**(5), 998-1006.

Griffin J.M. and P.R. Gregory (1976), "An Inter Country Translog Model of Energy Substitution Responses", *American Economic Review,* **66**(10), 845-857.

Griffin, J.M. (1977), "Long-run Production Modeling with Pseudo Data: Electric Power Generation", *Bell Journal of Economics,* **8**, 112-127.

Griffin, J.M. (1981), "Engineering and Econometric Interpretations of Energy-Capital Complementarity: Comment", *American Economic Review,* **71**(5), 1100-1104.

Griffin, K. (1974), *The Political Economy of Agrarian Change: An Essay on the Green revolution*. London: Macmillan.

Griliches, Z. and Lichtenberg (1984), "Inter-industry Technology Flows and Productivity Growth: A Re-examination", *Review of Economics and Statistics,* **66**(2), 324-329.

Hamid, M.A. (1977), "Study of the BADC Deep Tube-Well Programme in the North-Western Region of Bangladesh", Rural Development Studies Series No.7, Department of Economics, Rajshahi University, Bangladesh.

Hamid, M.A. (1982), "Shallow Tube-wells under IDA Credit in North-West Bangladesh: An Evaluation Study", Rural Development Studies Series No.10, Department of Economics, Rajshahi University, Bangladesh.

Hamid, M.A. (1984), "Low-Lift Pump under IDA Credit in South-East Bangladesh", Rural Development Studies Series No.12, Department of Economics, Rajshahi University, Bangladesh.

Hamid, M.A. *et al.* (1978), *Irrigation Technologies in Bangladesh: A study in Some Selected Areas,* Rajshahi: Department of Economics, Rajshahi University, Bangladesh.

Hossain, I. (1990) "Growth Performances of major agricultural crops, Regional Differences in Agricultural Productivity: Implications for Agriculture Planning in Bangladesh", *Bangladesh Journal of Political Economy,* **11**(1) 227-257.

Hossain, M. (1973), "*Farm-Size and Productivity in Bangladesh Agriculture: A Case Study of Phulpur Farms*", New Series No. 14, Dhaka: Bangladesh Institute of Development Economics.

Hossain, M. (1977),"Farm size, Tenancy and Land Productivity: An analysis of Farm Level Data in Bangladesh Agriculture." *Bangladesh Development Studies,* **5**(3), 285-348.

Hossain, M. (1986), Irrigation and Agricultural Performances in Bangladesh: Some Further Results", *Bangladesh Development Studies,* **14**(4), 37-56.

Hossain, M. (1987), "Agricultural Growth Linkages: The Bangladesh Case", *Bangladesh Development Studies,* **15**(1), 1-30.

Hossain, M. (1988), "*Nature and Impact of the Green Revolution in Bangladesh*", Research Report No.67, Washington DC: International Food Policy Research Institute/ Bangladesh Institute of Development Studies.

Hossain, M. (1991), *Agriculture in Bangladesh: Performance Problems and Prospects,* Dhaka: University Press Ltd.

Howes, M. (1985), *Whose Water?,* Dhaka: Bangladesh Institute of Development Studies.

Hulten, C. and R.M. Schwas (1984), "Regional Productivity Growth in US manufacturing, 1951-78", *American Economic Review,* **74**(1), 152-162.

Intrilligator, M.D. (1978), *Econometric Models, Techniques, and Applications*, N.J., USA, Prentice-Hall.

Islam, T.S. (1982), “Input Substitution and Productivity Change in Canadian Agriculture”, unpublished Ph.D. dissertation, University of Alberta, Canada.

Islam, T.S., M.I. Hossain and A. Habib, (1988), “Regional Difference in Factor Substitution in Bangladesh Agriculture”, *Bangladesh Journal of Political Economy*, **8**(1), June 1988, 102-106.

Jabbar, M.A. and M.S. Islam (1981), “Elasticity of Demand for Fertilizer and its Implication for subsidy”, *Bangladesh Journal of Agricultural Economics,* **4**(1), 47-57.

Jaim, W.M.H. and R.L. Sarker (1991), *Irrigation Issues in Bangladesh,* Proceedings of the workshop on human resource development program held at RDA, Bogra under the auspices of Winrock International, Dhaka and Rural Development Academy, Bogra.

Johnston, J. (1972), *Econometric Methods,* Tokyo: McGraw-Hill Kogakusha.

Jorgenson, D.W. (1984), “Role of Energy in Productivity Growth”, *American Economic Review,* **74**(2), 26-30.

Khalil, M.I. (1991), *The Agricultural Sector in Bangladesh: A Data Base,* Dhaka: US Agency for International Development.

Kiefer, N.M (1975), “Quadratic Utility, Labour Supply, and Commodity Demands”, Working Paper No.67, Industrial Relations Section, Princeton University.

Kmenta, J. (1971), *Elements of Econometrics,* New York: Macmillan.

Kuroda, Y. (1987), "Production Structure and Demand for Labour in Postwar Japanese Agriculture, 1951-82", *American Journal of Agricultural Economics,* **69**(2), 329-337.

Lau, L. (1974), "Comments on Application of Duality Theory", in M.D. Intrilligator, and D.A. Kendrick (eds.), *Frontiers of Quantitative Economics,* Vol.**2**, North-Holland.

Lawrence, D. and L. McKay (1980), "Inputs, Outputs and Productivity Changes in the Australian Sheep Industry", *Australian Journal of Agricultural Economics,* **24**, 46-59.

Lee, T. and Y. Chen (1978), "Agricultural Growth in Taiwan, 1911-1978", in Hayami, Y., V.W. Ruttan and H.M. Southwarth (eds.), *Agricultural Growth in Japan, Taiwan, Korea and the Philippines,* Honolulu: The University Press of Hawaii.

Lopez, R.E. (1980), "Structure of Production and the Derived Demand for Inputs in Canadian Agriculture", *American Journal of Agricultural Economics,* **62**, 38-45.

Magnus, J. and A.D. Woodland (1980), "Inter-fuel Substitution Possibilities in Dutch Manufacturing: A Multivariate Error Components Approach", Discussion Paper No.80-39, University of British Columbia, Vancouver.

Mandal, M.A.S. (1980), "Farm size, Tenure and Productivity in an Area of Bangladesh", *Bangladesh Journal of Agricultural Economics,* **3**(2), 21-42.

Matin, K.A. (1989), "Farm Size, Input Use and Productivity of Rice in Bangladesh", *Dhaka University Studies,* Part C, **10**(1), 37-49.

MCFadden, D. (1978), "The General Linear Profit Function", in Fuss, M. and D. McFadden (eds.), *Production Economics: A Dual Approach to Theory and Application,* Vol. **1**, 269-289, Amsterdam: North-Holland.

Merrifield, D.E and R.W. Haynes (1984), "Adjustment of Product and Factor Markets: An Application to the Pacific Northwest Forest Products Industry", *American Journal of Agricultural Economics* **66**(1), 79-87.

Mujeri, M.K. (1980), "Elasticity of Substitution between Jute and Synthetic Substitutes: An Econometric Estimate", *Bangladesh Development Studies,* **8**(3), 83-92.

Nadiri, M.I. and M.A. Schankerman (1981), "Technical Change, Returns to Scale and the Productivity Slowdown", *American Economic Review,* **71**(1), 314-319.

Norsworthy, J.R. and D.H. Malmquist (1983), "Input Measurement and Productivity Growth in Japanese and US Manufacturing", *American Economic Review,* **73**(5), 947-967.

Osmani, R.S. and M.A. Quasem (1985), "*Pricing and Subsidy Policies for Bangladesh Agriculture*", Research Monograph No.11, Dhaka: Bangladesh Institute of Development Studies.

Pesek, B. (1961), "Economic Growth and the Measurement," *Economic Development and Cultural change,* **9** (April): 295-315

Petzel, T.E. (1983), "Empirical Analysis of Soviet Agricultural Production and Policy: Comment", *American Journal of Agricultural Economics,* **65**(1), 175-177.

Pindyck, R.S. (1977), "Inter-fuel Substitution and the Industrial demand for Energy: An International Comparison", No.MITEL 77-026WP, Cambridge, MA: Massachusetts Institute of Technology.

Pindyck, R.S. and J.J. Rotemberg (1983), "Dynamic Factor Demands and the Effects of Energy Price Shocks", *American Economic Review,* **73**(5), 1069-1079.

Pollack, R.A., R.C. Sickles and T.J. Wales (1984), "CES-Translog: Specification and Estimation of a New Cost Function", *Review of Economics and Statistics,* **66**(4), 602-607.

Quasem, M.A. (1987), "Financial Return of Irrigation Equipment to Owners and Users: The case of STWs in Bangladesh 1981-85", DERAP Working Paper, Fantoftvegen 38-N-5036., Fantoft Bergen, Norway: CHR Michelsen Institute.

Rao, P. and R.L. Miller (1972), *Applied Econometrics,* New Delhi: Prentice-Hall of India.

Rushdi, A.A. (1982), "Factor Substitutability in the Manufacturing Industries of Bangladesh: An Application of the Translog Cost Model", *Bangladesh Development Studies,* **10**(2), 85-105.

Sav, G.T. (1984), "Micro Engineering Foundations of Energy-Capital Complementarity: Solar Domestic Water Heaters", *Review of Economics and Statistics,* **66**(2), 334-338.

Schluter, G. and P. Beeson (1981), "Components of Labour Productivity Growth in the Food System, 1953-67", *Review of Economics and Statistics,* **43**(3), 378-384.

Shahabuddin, Q. (1985), "Testing of Cobb-Douglas 'Myths': An Analysis with Disaggregated Production Functions in Bangladesh Agriculture", *Bangladesh Development Studies,* **13**(1), 87-98.

Shephard, R.W. (1953), *Cost and Production Functions,* Princeton, NJ: Princeton University Press.

Simmons, P. and D. Weiserbs (1979), "Translog Flexible Functional Forms and Associated Demand Systems", *American Economic Review,* **69**(5), 892-901.

Solow, J.L. (1987), "Capital-Energy Complementarity Debate Revisited", *American Economic Review,* **77**(4), 605-614.

Star, S. and R.E. Hall (1976), "An Approximate Divisia Index of Total Factor Productivity", *Econometrica,* **44**, 257-264.

Stevenson, R. (1980), "Measuring Technological Bias", *American Economic Review,* **70**(1), 162-173.

Sveikavskas, L. (1981), "Technological Inputs and Multi-factor Productivity Growth", *Review of Economics and Statistics*, **63**(2), 275-282.

Swain, P. and G. Friede (1976), "Die Entwicklung des Energieverbrauchsder Bundes republik Deutschland and der vereinigten staten von Amerika in Abhangigkeit von perisen and Technologie", Karlsruhe Institute Fur. Angewandte Systemanalyze.

Taslim, M.A. (1990), "The Explanation of the Inverse Size-Productivity Relation in Agriculture: A Critical Review", *Bangladesh Development Studies,* **18**(2), 77-86.

Thirtle, C.G. (1985), "Accounting for Increasing Land-Labour Ratios in Developmed Country Agriculture", *Journal of Agricultural Economics,* **36**(2), 161-169.

Tornqvist, L. (1936), "Bank of Finland Consumption Price Index", *Bank of Finland Monthly Bulletin,* **10**, 1-8.

USDA (1980), "Measurement of US Agricultural Productivity: A Review of Current Statistics and Proposals for Change", Technical Bulletin No.1614, Washington DC: US Department of Agriculture.

Uzawa, H. (1962), "Production relations with Constant Elasticity of Substitution", *Review of Economic Studies*, **26**, 291-299.

Veeman, T.S. (1975), "Economic Consequences and Policy Implications of the "Green Revolution" in India with Particular Emphasis on Water Resources Policy in Panjab," unpublished Ph.D dissertation, University of California, Berkeley.

Whittaker, J.M. (1983), "An Economic Analysis of Productivity Growth in U.K. Agriculture," unpublished M. Phill Thesis, University of Nottingham.

Wohlgenant, M.K. (1984), "Conceptual and Functional Form Issues in Estimating Demand Elasticities for Food", *American Journal of Agricultural Economics,* **66**(2), 211-215.

Wolff, E.N. (1985), "Industrial Composition, Inter-industry Effects, and the US Productivity Slowdown", *Review of Economics and Statistics,* **67**(2), 268-277.

World Bank (1990), *World Development Report* 1990, Washington DC: Oxford University Press.

Wyzan, M.L. (1981), "Empirical Analysis of Soviet Agricultural Production and Policy", *American Journal of Agricultural Economics,* **63**, 475-483.

Wyzan, M.L. (1983), "Empirical Analysis of Soviet Agricultural Production and Policy: Reply", *American Journal of Agricultural Economics,* **65**(1), 178-180.

Zellner, A. (1962), "Efficient Method of Estimating Seemingly Unrelated Regressions and Tests of Aggregate Bias", *Journal of American Statistical Association,* **57** (June), 348-368.