

Factor Substitution and Technical Change in Bangladesh Agriculture

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This empirical study on factor substitution and technical change in Bangladesh agriculture uses the translog cost function which belongs to the family of flexible forms and does not *a priori* restrict the value of the elasticity of substitution. Using the function, both substitutability and complementarity relationships between inputs are found in Bangladesh agriculture. Most of the own elasticities of demand for farm inputs are found to be less than one. There are also evidence of land and labour saving technical changes and presence of fertiliser and irrigation using technical changes.

Keywords: Translog Cost Function, Factor Substitution, Technical Change, Bangladesh Agriculture

Jel Classification: D04, D23, D24, O33, Q16

I. INTRODUCTION

Since the emergence of Bangladesh as an independent country in 1971, 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. As a predominantly agricultural country, all important activities depend on the agricultural sector. In the post-independence period, a rapid expansion of irrigation, fertiliser and modern variety (MV) seeds caused a breakthrough in Bangladesh agriculture and Bangladesh made steady progress in crop production. In this study, an attempt is made to examine whether labour has been substituted by non-durable inputs such as fertiliser and irrigation.

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

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unity. The CES function made a major advance in factor substitution study by allowing factor substitution of different magnitudes (0 to $+\infty$). 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 ($-\infty$ to $+\infty$), is known as flexible forms. The most well-known and widely used of these is the translog function. As 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. In this study, four inputs of land (N), labour (L), fertiliser (F), and irrigation (I) are considered.

The specific objectives of this study are: (1) to measure factor substitution in terms of Allen partial elasticities of substitution (AES); (2) to examine changing input demand by estimating own and cross price elasticities of demand; (3) to show the strength of nonhomotheticity; and (4) to analyse the nature of technical change in Bangladesh agriculture.

II. SELECTIVE FLEXIBLE FORM STUDIES IN THE AGRICULTURE SECTOR: A REVIEW

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 and he found both substitutability and complementarity relationship between different inputs and found clear evidence of biased technical change in the US agriculture. Brown (1978) estimated translog production to study factor substitution and factor productivity in the US agriculture. In the econometric analysis of factor substitution, Brown found capital-labour and labour-material pairs to be substitutes while capital and material were found to be complements. Chotigeat (1978) used the homothetic translog production function to study factor substitution and input demand in Thai agriculture and he found capital-fertiliser and capital-labour pairs to have substitution relationship while a relationship of complementarity existed in the fertiliser-labour pair. Elasticity of substitution values was obtained which were different from unity. Wyzan (1981) used the translog production functions to the Soviet agricultural sector. Wyzan found substitution possibilities between land and labour.

Islam (1982) applied the translog function to study factor substitution and technical change in Canadian agriculture. He found substitution and complementarity relationship between the factors and 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 fertiliser-using biased

technical change was found. Akridge and Hertel (1986) used the translog cost function to explain the relationship between cost and output for the retail fertiliser plants. In this study it was found that by increasing and diversifying the output, the fertiliser plants could lower average cost. Kuroda (1987) estimated a non-homothetic translog cost function for the Japanese agriculture sector and 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 was observed. Ali (1991) applied the translog function to study factor substitution in the UK agriculture. He found both substitutability and complementarity relationship between the inputs. All own price elasticities of demand were found negative. Land-labour, land-fertiliser, labour-machinery and fertiliser-energy were found to be Allen substitutes while machinery and energy emerged as complements. The study indicated a very high degree of substitutability between fertiliser and energy. Evidence of machinery-saving and fertiliser-using technical changes was found in UK agriculture.

The above research works cover Translog cost function related to agriculture sector in different countries. By using Translog cost function, no such study has been conducted so far to examine both substitutability and complementarity between agricultural inputs in Bangladesh agriculture sector. The present study is conducted to fill this research gap.

III. THE THEORETICAL MODEL

3.1 The Basic Translog Cost Function

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:

$$\ln C = a_0 + a_Y \ln Y + \frac{1}{2} \gamma_{YY} (\ln Y)^2 + \sum_i a_i \ln P_i + \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln P_i \ln P_j + \sum b_{Yi} \ln Y \ln P_i \quad (1)$$

where C = total cost

Y = aggregate output

P = prices of inputs

The possibilities of augmented technical change have not been included in equation (1). Incorporating the technical change by including time (t), equation (1) can be modified as:

$$\begin{aligned} \ln C = & a_0 + a_Y \ln Y + \frac{1}{2} \gamma_{YY} (\ln Y)^2 + \sum_i a_i \ln P_i \\ & + \frac{1}{2} \sum_i \sum_j \gamma_{ij} \ln P_i \ln P_j + \sum b_{Yi} \ln Y \ln P_i \\ & + \varphi_t t + \frac{1}{2} \varphi_{tt} t^2 + \varphi_t Y^t \ln Y + \sum_i \varphi_t P_i t \ln P_i \end{aligned} \quad (2)$$

Equation (2) considers technical change at a constant rate and it can indicate direction of technical change.

3.2 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-minimising share equations for the various inputs can be obtained by logarithmically differentiating equation (2) with respect to input prices. Now the derived demand equations and the cost-share equations can be presented as:

$$\frac{\delta \ln C}{\delta \ln P_i} = S_i = a_i + \sum_j^n \gamma_{ij} \ln P_j + b_{Yi} \ln Y + \varphi_t P_i t \quad (3)$$

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

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,

$$\begin{aligned} \sum_i a_i &= 1 \\ \sum_i \gamma_{ij} &= 0 \\ \sum_i b_{Yi} &= 0 \\ \sum_i \varphi_t P_i &= 0 \end{aligned} \quad (4)$$

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

$$\sum_j \gamma_{ij} = 0 \quad (5)$$

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

$$\gamma_{ij} = \gamma_{ji} \quad (6)$$

Considering the above-stated restrictions which are placed on equation (3), different production structures can be reflected. In this study, the non-homothetic structure with technical change has been empirically estimated.

3.3 Elasticities of Substitution and Demand

In the cost shares equations, the estimated gamma coefficients do not have any clear economic meaning but are translated into Allen partial elasticities of substitution (AES) and price elasticities of factor demand (ED). Uzawa (1962) has demonstrated that the AES between two inputs i and j can be expressed as:

$$\sigma_{ij} = \frac{C_i C_{ij}}{C_i C_j} \quad (7)$$

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 (7) has been given in general terms. Now for the translog cost function, the AES is given by

$$\sigma_{ij} = \frac{\gamma_{ij} + S_i S_j}{S_i S_j} \quad (8)$$

The own price elasticity is given by the following equation

$$\sigma_{ii} = \frac{\gamma_{ii} + S_i^2 - S_i}{S_i^2} \quad (9)$$

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

$$ED_{ij} = S_j \sigma_{ij} \quad i \neq j \quad (10)$$

$$ED_{ii} = S_i \sigma_{ii} \quad (11)$$

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

IV. THE DATA

Time series data from 1973 to 1995 for Bangladesh agriculture sector is considered in this study. Data on price and quantities of output and inputs have been used. To obtain the cost of land, the sum of opportunity cost of land and real estate taxes are included. In calculating the opportunity cost over the entire period, the choice of 5 per cent is considered as the fixed rate of interest. Such a rate was used earlier by Binswanger (1973) and Islam (1982). The cost of land is estimated by multiplying the price of land by quantity of land. To obtain the cost of labour, persons employed in agriculture sector are multiplied by yearly wages. The data on annual consumption of Urea, Triple Super Phosphate, and Muriate of Potash are used in this study from published sources. Considering the prices of fertiliser by type, the costs of fertiliser are derived as the annual consumption of fertilisers multiplied by the corresponding year's prices. Irrigation costs are defined as the sum of expenses on individual irrigation modes such as low lift pumps (LLPs), deep tubewells (DTWs), and shallow tubewells (STWs). To obtain the costs of irrigation, the area irrigated by various methods is multiplied by operating and maintenance cost paid by farmers for the respective modes.

Time series data on price and quantities of inputs and output have been compiled from official government sources, Bangladesh Bureau of Statistics (BBS, *Statistical Yearbook of Bangladesh*, *Yearbook of Agricultural Statistics*, and *Monthly Statistical Bulletins*, various issues). In the case of prices of output, the harvest price of major agricultural crops is used. In constructing the quantity

index of all agricultural output, composition of 25 crops is considered to obtain the aggregate crop index. For constructing the price and quantity indexes by using the yearly data, Divisia indexing method is employed in this study and it is considered appropriate for the translog function (Christensen 1975, Diewert 1976).

V. EMPIRICAL ESTIMATES OF FACTOR SUBSTITUTION AND TECHNICAL CHANGE

The estimated coefficients of the derived demand functions for non-homothetic structure with technical change are presented in Table I.

TABLE I
ESTIMATES OF DERIVED INPUT DEMAND FUNCTIONS: NON-HOMOTHETIC STRUCTURE WITH TECHNICAL CHANGE

Equation	Land	Labour	Fertiliser	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
Fertiliser			-.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. Coefficients significant at the 1% and 5% levels are denoted by two and one asterisk (s) respectively. Figures without t-values were obtained by using the adding up restrictions.

Table I reveals that seven of the nine estimated price coefficients are statistically significant. The standard error of estimates is very low. The R² 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 implies 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. Among the three estimated share equations, two estimated coefficients on the time variable are statistically significant at the five per cent level of significance. That is, there is some evidence of technical changes. In the land and labour equations,

the sign of the time coefficients is 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 fertiliser and the irrigation equation which indicates the existence of fertiliser and irrigation using technological changes in Bangladesh agriculture. These results are consistent with the present nature of input use in the Bangladesh agriculture sector. The estimated input price coefficients are converted into Allen partial elasticities of substitution (AES) and these AES are reported in Table II.

TABLE II
ESTIMATES OF PARTIAL ELASTICITIES OF SUBSTITUTION: NON-HOMOTHETIC STRUCTURE WITH TECHNICAL CHANGE

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

Table II indicates that among the six pairs of inputs, both land-fertiliser and fertiliser-irrigation input pairs appeared as substitutes. Complementarity relationship prevailed for other four pair of inputs. The appearance of complementarity of land-labour, land-irrigation, labour-fertiliser and labour-irrigation input pairs are found. A high degree of substitutability between fertiliser and irrigation is found. The estimated price elasticities of input demand (ED) are given in Table III.

TABLE III
ESTIMATES OF OWN AND CROSS PRICE ELASTICITIES OF DEMAND: NON-HOMOTHETIC STRUCTURE WITH TECHNICAL CHANGE

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

Table III reveals that except the value of fertiliser, 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 fertiliser. Here own price ED of fertiliser is the highest followed by those of

irrigation, land and labour. It seems that the demand for fertiliser is more responsive to own price changes than those of other inputs.

5.1 Trends of Input Relationships

Since the entire study period is considered, it enabled us to know whether fertiliser-irrigation substitution relationship declined significantly in the latter years in spite of the high irrigation cost due to high energy prices. The values of the Allen partial elasticities of substitution estimates for the period 1973-1995 are presented in Table IV.

TABLE IV
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
1978	0.079	0.041	-0.079	-0.011	-0.016	29.733
1983	0.045	0.065	-0.030	-0.002	0.001	15.807
1988	-0.173	0.077	-0.067	0.002	-0.001	14.286
1993	-0.458	0.108	-0.076	0.012	0.005	9.688
1995	-0.509	0.105	-0.081	0.011	0.005	10.267

Note: N-L=Land-Labour; N-F=Land-Fertiliser; N-I=Land-Irrigation; L-F=Labour-Fertiliser; L-I=Labour-Irrigation; F-I=Fertiliser-Irrigation.

In Table IV, 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 fertiliser-irrigation showed significant decline in the latter years. Substitution between land and fertiliser showed a large increase in the latter period. The estimated input cross elasticities of demand are reported in Tables V and VI.

TABLE V
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
1978	0.0539	0.0008	-0.0009	-0.0002	-0.0002	0.3300
1983	0.0292	0.0017	-0.0007	-0.0001	0.0000	0.3810
1988	-0.1196	0.0021	-0.0014	0.0001	0.0000	0.3014
1993	-0.3233	0.0037	-0.0019	0.0004	0.0001	0.2383
1995	-0.3625	0.0035	-0.0020	0.0004	0.0001	0.2536

TABLE VI
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
1978	0.0232	0.0120	-0.0231	-0.0078	-0.0110	0.5590
1983	0.0136	0.0197	-0.0091	-0.0015	0.0010	0.4157
1988	-0.0449	0.0199	-0.0174	0.0016	-0.0006	0.3943
1993	-0.1075	0.0254	-0.0180	0.0084	0.0034	0.3284
1995	-0.1175	0.0242	-0.0186	0.0076	0.0036	0.3378

In Table V, it is observed that two of the six estimates of ED showed some decline over the latter period. Table VI shows the absolute value of the ED where estimates for all input pairs except fertiliser-land displayed a declining tendency. Thus, from these estimates, it can be observed that considerable changes occurred in input relationships in Bangladesh agriculture over time.

From this analysis, it can be noted that the estimates of AES between fertiliser and irrigation indicated a significant decline over the latter years. This means that, both the use of fertiliser 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 fertiliser than irrigation due to high irrigation costs.

About the rising tendency of land-fertiliser substitution, it seems that a moderate increase in cultivated land might have caused the increasing consumption of fertiliser to a great extent in Bangladesh agriculture to enhance agriculture production. Of all the positive cross-price elasticities, the highest fertiliser-irrigation cross price elasticity was found and it gradually declined over time. It seems that in the early years, the demand for fertiliser was more responsive to the changes in the irrigation prices than that to other input prices but over time this responsiveness tended to decline.

VI. POLICY IMPLICATIONS AND CONCLUSIONS

This study dealt with factor substitution and technical change in the Bangladesh agricultural sector for the first two decades after independence. During this period, important changes occurred in the production process. The estimates of elasticities of substitution showed considerable factor substitution (and complementary) and there is existence of technical change. An interesting feature is that land and labour saving technical changes and fertiliser and

irrigation using technical changes were observed during the sample period. This suggests that it is essential to increase the use of both land and labour simultaneously. In this situation, in order to increase the cultivable cropland, government can undertake policy measures about the culturable waste, investment in coastal areas, maintenance of soil health, overhaul the extension system, etc.

The estimates of AES for different sub-periods changed in magnitude but mostly not in sign. This study also shows that there is a gradual decline in fertiliser-irrigation substitutability, which implies that farmers are using both fertiliser and irrigation due to gradual awareness of the benefits of these inputs despite increasing prices of these inputs. An important policy implication of this development is that input subsidy policy should not be abandoned abruptly but subsidies may be gradually phased out if called for.

However, the translog model performed fairly well under a multi-input production framework and the non-homothetic structure with technical change adequately explained the characteristics of Bangladesh agriculture. In this study, the aggregate agriculture sector of Bangladesh has been considered to explain the nature of factor substitution. There is scope for further research to analyse the nature of factors substitution and technical change in the country.

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