Pakistan Journal of Applied Economics, (1989), Vol.VIII No.2, (135–156)

MARGINAL PRODUCTIVITIES, SUBSTITUTES AND COMPLEMENTS IN BANGLADESH AGRICULTURE

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This paper quantifies the rates of return of different agricultural inputs, and studies whether labour and fertilizers are substitutes or complements. The study uses detailed farm level data based on the survey conducted by the International Food Policy Research Institute and Bangladesh Institute of Development Studies, covering sixteen villages in 1981-82. Different definitions of substitutes and complements are used. We find that the use of a price definition for classifying inputs as substitutes and complements is not possible when some of the inputs are not purchased in a market place. On the basis of a quantity definition, (Fisher's), fertilizer and labour are complements.

Introduction

The various inter-relationships between labour and fertilizer and their rates of return in Bangladesh agriculture is an issue of enormous importance. This paper investigates and quantifies the rates of return of different agricultural inputs and explores whether labour and fertilizer are substitutes or complements. Most policy makers are interested in the estimation of the rates of return on different agricultural inputs. In this paper, the marginal physical productivity of each of the inputs is estimated from crop level yield relationships. The hypothesis whether the marginal physical productivities among different HYV crops is equalized can be tested. The extent to which the allocative ratio or the rate of return differs from unity can be studied and suitable policies devised to increase the level of the under used inputs.

* The author wishes to thank Andrew Bernard for his competent statistical assistance and the referees of the journal for their helpful comments. This paper is based on the survey conducted by IFPRI/BIDS team in Bangladesh and the author is grateful to IFPRI for permitting him to use the data.

The issue of input substitutability – complementarity is of interest to both theoretical and applied economists, and given most of the controversy in analytical models, a micro level study could help in sharpening conclusions from theoretical frameworks. Sen (1975) and Stiglitz (1969) obtain different analytical results in their models as the former generally treats family and hired labour as substitutes, while the latter largely assumes complementarity between family and hired labour. Various definitions of substitutes – complements are presented in this paper. We choose the one using uncompensated price derivative, because it is impossible to obtaining price data on other inputs except fertilizer and hired labour on Bangladesh survey data.[1]

The issue of aggregation is at the heart of most econometric estimations. It is thus necessary to compare the results of the allocative ratio from the aggregated value of yield functions with the weighted average of the allocative ratio from the disaggregated yield (physical) relationships using exogenous prices. An interesting hypothesis to test is the extent to which allocative ratios from labour and fertilizer differ significantly from unity.

This study is organised into four sections. In the first section, we discuss the data and yield regressions for individual crops and marginal physical productivities for individual crops. Aggregate yield relationships in value terms are estimated from cross-section data of 465 farms for the year 1982. The marginal value productivity is obtained and compared with the input price. In section II, various definitions of substitutes and complements are given, these are important as economists largely tend to use the price definition. One of the difficulties in developing agriculture is the issue of non-purchased inputs, for which relevant price is the shadow price which is unobserved. In section III, we estimate fertilizer consumption relationship at an aggregate level using cross-section data. In reality, yield and input relationship ought to be estimated simultaneously, but given that only two input prices are available, simultaneous equation estimation is not plausible, as the specified relationships would remain under identified. Summary and conclusions are presented in section IV.

Section I

In this section, description of the data and the estimation of yield per acre relationships are presented.

Description of the Data

The basic data were derived from a survey conducted in Bangladesh between

[1] Full description of the data will be published by the IFPRI.

1981-82. The sample covered a total of 462 farms from sixteen different villages located in five 'environmental regions' classified as (a) Red Soil Deep Brown (b) Highland Ganges Project (c) Saline Soil (d) Developed Area with High Infrastructure and (e) Flood Plain. The survey collected data on a range of socio-economic variables.

For each farm, levels of inputs and yields per acre of land were recorded. There was no information on the composition of crop varieties for individual plots. In the case of paddy, inputs and yields per acre were available for both local crop varieties and HYV. Prices of inputs and outputs were not available at the farm level. However, in some cases, price indices were derivable from information on value and volume. It is assumed that crop prices are uniform for all farmers which seems plausible given the negligible variation in the unit value of the marketed output. It also seems unlikely that intra-village fertilizer prices vary and changes in observed prices are most likely due to the aggregation of value measures for different fertilizer types and changes in fertilizer prices through the year. It should be noted that some inputs such as manures are likely to contain heterogenous nutrients. Data on bullock labour costs per acre include hired labour costs, but exclude associated family labour time. Value data on fertilizer inputs were used because of nutrient differences.

In Bangladesh, about 80 per cent of the total cropped acreage is allocated to rice during the three seasons: Aus, Aman and Boro. Aus rice is sown between April and June and harvested in July and August. Boro rice is transplanted in December, January and February and harvested during the months of April, May and June. Aman rice is transplanted in July and August or sown in May and June. Both Boro and Aman are harvested in December or January. Since the Boro and the Aman seasons overlap, HYV Boro competes for land with the traditional (local) Aus. The use of the local Aus crop has declined steadily during recent years.

The results on dummies for sixteen villages used in the regression equation are reported in Table 1. The village dummies DV9, DV10, DV11, DV15 and DV16 refer to villages in unfavourable environments. With the exception of DV11, where HYV Boro was adopted, no HYV's were employed in these villages. Further information on villages is given in Parikh (1990).

Estimation of Yield per Acre Relationships

For three HYV crops and another eight crops, yield relationships were estimated. The yield equations were estimated because the log linear production function was not possible to estimate using the entire set of data. Moreover, the evidence on constant returns to scale was strong, hence it was decided to estimate yield per acre relationships. If total input data are used to relate with total output, multicollinearity among inputs is so strong that it is not possible to derive significant effect of any input other than acreage. Use is made of value data on fertilizer, as the

TABLE 1

Yield per Acre for Different Crops
(Regression Coefficients, t-Ratios, R^2 and SEE)

	Constant	FVA	HLA	FLA	MNRA	BLA	DV1	DV2	DV3	DV5
LOCAL AUS	12.3373	0.01314	0.0136	-0.03126	0.0212	-0.00750		-5.4437	4.87371	-1.6314
	(2.455)	(1.98)	(0.367)	(1.552)	(3.159)	(1.512)		(1.069)	(0.959)	(0.315)
HYV AUS	37.012	0.02279	0.01657	0.04284	0.0038	0.01661	*	-30.3367	-9.7134	-30.3367
	(12.742)	(3.779)	(0.378)	(2.097)	(0.412)	(2.218)		(12.81)	(2.457)	(12.81)
LOCAL AMAN	14.057	-0.00204	0.1104	0.1303	-0.0806	-0.00355	0.0713	-1.636	*	-11.5066
	(4.472)	(0.278)	(4.386)	(2.947)	(1.711)	(0.27)	(0.017)	(0.353)		(0.769)
HYV AMAN	27.7594	0.0111	0.3474	0.1466	-0.021	0.01944		-8.3938	-13.1562	-16.8941
	(11.132)	(2.501)	(15.385)	(3.879)	(1.274)	(2.874)		(1.94)	(2.597)	(7.378)
HYV BORO	44.044	0.01443	0.0208	0.0285	-0.00824	0.00408		6.1374	-0.3067	
	(9.924)	(1.946)	(0.372)	(1.192)	(0.789)	(0.623)		(1.872)	(0.069)	
WHEAT	10.44	0.000304	0.2383	0.1076	0.00346	0.00739				-4.2699
	(3.485)	(0.072)	(2.271)	(2.284)	(0.373)	(0.782)				(1.336)
OILSEEDS	11.3563	-0.0286	0.1731	0.1561	0.0292	-0.00355	-3.777			10.296
	(1.479)	(1.347)	(0.839)	(1.859)	(1.394)	(0.239)	(0.667)			(1.319)
JUTE	6.2726	-0.00082	0.0266	0.0125	0.00434	-0.006	10.378	6.843	6.909	5.865
	(1.778)	(0.198)	(1.945)	(1.214)	(1.13)	(1.557)	(2.92)	(2.109)	(2.073)	(1.731)
SUGARCANE	187.65	0.1872	1.209	0.7725	0.1894	0.1158			205.81	*
	(2.007)	(1.277)	(1.136)	(1.67)	(0.774)	(1.215)			(2.42)	

TABLE I

(Continued)

	DV6	DV7	DV8	DV9	DV10	DV11	DV13	DV14	DV15	R^2/SEE	N
LOCAL AUS	-1.738 (0.349)	-6.2212 (0.924)	-2.9497 (0.58)				1.1698 (0.2)			0.38765/4.3599	128
HYV AUS		-10.0108 (5.816)								0.7561/6.259	085
LOCAL AMAN		6.3952 (0.472)	-7.4162 (1.675)	2.6503 (0.552)	6.2463 (1.379)	3.6315 (0.741)	-6.8596 (1.543)	4.5796 (0.862)		0.17516./13.1667	145
HYV AMAN	-20.9296 (5.087)	*					-26.6334 (11.356)	-11.5427 (5.561)		0.9233/8.009	130
HYV BORO						-2.334 (0.583)	-15.827 (4.841)	-3.658 (1.207)	15.6319 (4.406)	0.4423/8.5818	146
WHEAT	-3.3913 (1.22)		-7.3256 (2.592)							0.1965/5.6523	067
OILSEEDS	-8.675 (1.161)		-12.338 (1.626)						3.4338 (0.572)	0.2085/13.1698	109
JUTE	6.813 (2.018)	8.899 (2.573)	4.848 (1.46)			22.451 (5.263)			14.794 (4.269)	0.4013/4.113	170
SUGARCANE	121.19 (1.968)		-10.839 (0.086)							0.047/187.80	069

Explanation on Symbols:
FVA = Value of fertilizers per acre (takas); HLA = Hired labour per acre (number of days); FLA = Family labour per acre (number of days);
MNRA = Value of manures per acre (takas); BLA = Bullock costs per acre (takas); DV1...DV15 are village dummies.
Note: *Current village replaces village 16 as the base village.
No village dummies for village 4 and 12 were used. Both these villages were in poor infrastructure regions.

survey data revealed that due to fertilizer nutrient differences price per nutrient content did not vary from village to village and farm to farm. The variations in fertilizer prices were due to aggregation of different nitrogenous and potassic fertilizers. Given the aggregation problem, either the fertilizer quantity index or the value of fertilizer can be used. There were difficulties with the fertilizer quantity index because the data were sometimes recorded in bags rather than kilograms or pounds. With a value measure, this problem can be overcome. The marginal physical productivity of fertilizer is under-estimated through the ratio of marginal physical output to the value of fertilizer when elasticity of demand for fertilizer with respect to fertilizer price is less than unity. It can be seen that

$$\frac{\partial Q}{\partial FQA} = \frac{\partial Q}{\partial FVA} \text{ [Fertilizer price } (1 - \eta)] \qquad (1)$$

η is the fertilizer demand elasticity with respect to fertilizer price, while Q, FQA and FVA are physical output, fertilizer quantity per acre and cost of fertilizer used per acre, respectively.

It can also be seen that yield per acre equations have some inputs measured in value and others in physical units. It should be mentioned that price is constant on a cross-section data; this is especially true for fertilizer during the period 1981-82, when the government had a subsidy scheme with the fertilizer price being fixed. For other inputs such as manure or bullock costs, it was heterogeneity of inputs which resulted in the use of value data rather than physical input information. For HYV Aus, coefficients on fertilizer, family labour and bullock costs are significant, while for HYV Aman, coefficients of fertilizer, hired labour, family labour and bullock labour costs are significantly different from zero. For HYV Boro, the winter crop, fertilizer is the most important input. In all cases, village dummies have been used. For wheat, jute and oilseeds, the fertilizer input is insignificant. The cropwise yield per acre regressions indicate farmers' choice ex-post, and this choice of the crop is dependent upon farmers' own environment (reflected in village dummies, capturing both infrastructure and the environment), subsistence needs and technological constraints. It is very unlikely that the majority of farmers can grow three crops given the duration, soil and other considerations, such as risk. The purpose of cropwise regression is to obtain marginal productivity at the crop level for each of the inputs. There are differences between marginal productivities of hired labour and family labour and of fertilizer across different crops. A general theory where crop duration is built in economic profit maximization is not available at present. Seed-fertilizer-water technology will change the cropped area because of multiple cropping induced by short duration varieties. This seems to have already happened in Bangladesh.

Table 2 shows significant marginal physical productivities for each crop and a

TABLE 2

Marginal Physical Productivity of Fertilizers, Hired Labour, Family Labour, Bullock Labour and Manures

Name of the Input	Crop/Season	Marginal Physical Productivity	Marginal Value Productivity[b]	Allocative Ratio from Weighted Average[f]
Fertilizers[a] (measured in value)	Local Aus	0.01314[a]		
	HYV Aus	0.02279[a]		
	HYV Aman	0.01111[a]		
	HYV Boro	0.01443[a]		
	Weighted Average	0.01526[a]	2.2127	2.2127
	Aggregate Yield Relationships			3.401 (1.903)[e]
Hired Labour[c]	Local Aman	0.1104		
	HYV Aman	0.3474		
	Wheat	0.2383		
	Jute	0.0266		
	Weighted Average	0.1792	25.984	1.416
	Aggregate Value of Output per Cropped Acre			2.2283 (1.2468)[e]
Family Labour[c]	HYV AUS	0.0428		
	Local Aman	0.1303		
	HYVAman	0.1466		
	Wheat	0.1076		
	Oilseeds	0.1516		
	Weighted Average	0.1063	15.4135*	0.8402
	Aggregate Value of Output Cropped per Acre			1.7257 (0.9657)[e]
Bullock Labour[d] (measured in value)	HYV Aus	0.0166		
	HYVAman	0.0194		
	Weighted Average	0.0182	2.639	2.639
Manures[a]	Local Aus	0.0212[a]		
	Weighted Average	0.0212[a]	3.074	3.074

Notes:

[a] Fertilizer and manure were measured in value terms and, therefore, we can only obtain marginal physical productivity divided by price of fertilizer denoted as marginal physical productivity of one taka worth investment in fertilizer and manure separately.

[b] Marginal value productivity is obtained by multiplying each of the MPP by rice price, assumed to be 145 taka per maund.

[c] For hired labour and family labour we have used the average daily wage of 18.34 taka in working out allocative ratio.

[d] The coefficient on bullock labour is biased because family labour is included in the bullock cost, while hired labour used for bullock ploughing is not accounted for in bullock cost.

[e] Bracketed figures denote the allocative ratio adjusted for sown area by using mean cropping intensity of 1.7870. Each of the allocative ratios are divided by cropping intensity.

[f] Where more than one crop is involved, relative values of crop are used as weights.

weighted average based on relative yield or total physical yield (for rice crop) or value. The table, shows that the allocative ratio for fertilizer is about 2.21, derived as a weighted average of fertilizer productivity times the rice price of 145 taka per maund. When this is compared with the marginal productivity per unit value of fertilizer, derived from the aggregate crop value (cropped acre) relationship, we find a discrepancy.[2] This is because the value of cropped output contains different mixture effects of eleven crops (maximum three) during the year. In addition, we did not relate the value of cropped output per cropped acre directly with all the inputs, but subtracted the cost of bullocks, seeds, pesticides and irrigation. This method was used for two reasons: (a) to remove multicollinearity between inputs and (b) to remove biases in the estimates of costs as discussed in the appendix e.g., irrigation costs were sometimes borne by farmers in some villages, while in others they were borne by the government, and different systems prevailed with respect to irrigation water. The adjusted value of output per cropped acre was used as a dependent variable and the following relationship was obtained:

$$\begin{aligned} VVADJA_i = \; & \underset{(2.427)}{630.6408} - \underset{(0.546)}{13.4262DINF_i} + \underset{(8.619)}{40.862HLA_i} - \underset{(2.398)}{2.6336MNRA_i} \\ & + \underset{(8.637)}{31.6488FLA_i} + \underset{(6.610)}{3.4015FVA_i} + \underset{(5.377)}{146.760CROPIN_i} \qquad (1.2) \end{aligned}$$

[2] A crop level weighted average of productivity actually produces productivity per sown acre since cropped acre equals sown acre for a single crop. In the light of this, it is preferable to compare aggregated sown acre productivity to the weighted average. However, since sown acreage figures were not collected directly, we did not estimate those equations. Instead numbers in parentheses in Table 2 offer derived aggregate productivity estimates per sown acre.

$$R^2 = 0.3574 \qquad SEE = 1551.49$$
$$F = 41.7119 \qquad n = 457$$

When a similar relationship was attempted as a Cobb-Douglas double logarithmic relation, we lost about 200 observations. The estimated relationship is :

$$\log VVADJ_i = \underset{(20.896)}{6.9538} - \underset{(0.074)}{0.0008 DINF_i} + \underset{(21.446)}{1.0250 \log A_i} - \underset{(0.556)}{0.0249 \log HLA_i}$$
$$+ \underset{(3.3230)}{0.5939 HYVA_i} - \underset{(0.637)}{0.0309 \log MNRA_i} + \underset{(1.009)}{0.0567 \log FLA_i}$$
$$+ \underset{(3.256)}{0.1211 \log FVA_i} \qquad (1.3)$$

$$R^2 = 0.6917 \qquad SEE = 0.5398$$
$$F = 80.7676 \qquad n = 260$$

The purpose is to show that a log linear relationship is unsuitable for this study. All inputs are in per acre[3] terms while output is value per acre.

Constant returns to scale is not rejected by (1.3), and the yield per cropped area relationship can be used for further analysis. We obtained marginal value productivity of hired labour as 40.86 and, given the wage rate per day as 18.44 taka, we obtained 2.228 as the allocative ratio. If this is compared with average crop level estimated allocative ratio, this is an overestimate, but when it is adjusted for net sown area, by using cropping intensity of 1.78, we obtained 1.2468 taka for hired labour. Given the nature of the data, such detailed comparisons on point estimates will not be valid and, therefore, we can simply infer that some consistency is achieved between the results on MVP and the allocative ratio derived from the weighted average of crop relations versus the aggregate production function. Our ordinal ranking on fertilizer, hired labour and family labour remains the same in the sense that fertilizer has the highest rate of return, followed by hired labour, with family labour scoring the lowest rank if market wage is used for imputing family labour.

It is worthwhile to mention that our efforts at estimating the aggregate adjusted value of output *per net sown area* did not bear fruit. Using data for 461 farms we found that cropping intensity was the most dominating variable explaining variations in the value of output per sown acre. It appeared to have endogenized cropping

[3] The definitions are: VVADJ = Adjusted value of output per acre, DINF = Infrastructure index, HLA = Hired labour per acre (days), MNRA = Value of manures per acre, FLA = Family labour in days per acre, FVA = Value of fertilizer per acre, HYVA = HYV area proportion and CROPIN = Cropping intensity index.

intensity through environment dummies and inputs per acre, but this is not borne out by the results. It seems that cropping intensity must be explained by the HYV, which has probably a shorter gestation period, implying that multiple cropping is induced by technological factors. We were surprised to find that the simple correlation between cropping intensity (cropped area divided by net sown area) and adjusted output per sown area was 0.97 on 461 observations.[4] As a result, we had to abandon this attempt and look for micro and macro consistency through the cropping intensity index used exogenously for making comparisons on the allocative ratio.

Allocative efficiency can be compared among crops but this assumes perfectly competitive factor market, and our a priori view goes against this assumption. We are using the concept of neoclassical profit maximization, though it is implausible that agricultural product and factor markets in Bangladesh are perfectly competitive. Hence, we do not make that assumption. It should be pointed out that yield relationships for various crops could be joint relationships, as the choice of the crop during the year would be endogenous. Given the data imperfections, we choose to estimate them as single equation relationships rather than seemingly unrelated equations using tobit estimation, since the yield for crops not grown during some season will be zero. This raises the question that area, fertilizer and labour input decisions are also endogenous and hence all crop relationships with inputs should be treated simultaneously. A complete simultaneous equation model with all crops and inputs being endogenous will be impossible to estimate without sufficient number of exogenous variables, i.e., price variables.

Section II

In this section, various definitions of substitutes and complements used in our study are summarised.

Definitions of Substitutes and Complements

Before 1934, three common definitions of substitutes and complements were used, these are: (1) Fisher's (1982), (2) Pareto-Georgescu-Roegen's [Pareto, (1909)], and (3) the sign of cross price effects in input demand equations. The first definition of complements is pre-historic, but a definitive formulation was given by Irving Fisher. Perfect complements are defined as occurring when contours CCC are obtained in input space and perfect substitutes are obtained when contours SS are observed. Tea and coffee are substitutes, while tea and lemon are complements. The use of this concept is made in the present study when fertilizer is related with labour.

[4] Data on net sown area were not observed and it was estimated from cropped area.

If in a regression of fertilizer consumption on labour a positive and significant coefficient is obtained, the two are complements. A negative and significant coefficient implies that fertilizer and labour are substitutes. Only polar cases can be analysed this way, with many weaknesses present in this definition.

Pareto-Georgescu Roegen's definition examines the sign on $\delta^2 y/\delta q_1 \delta q_2$ (the second cross partial derivative) where y is output and q_1 and q_2 are quantity of inputs 1 and 2 respectively. If the coefficient is less than zero then the inputs are substitutes, while a zero value indicates that they are independent.

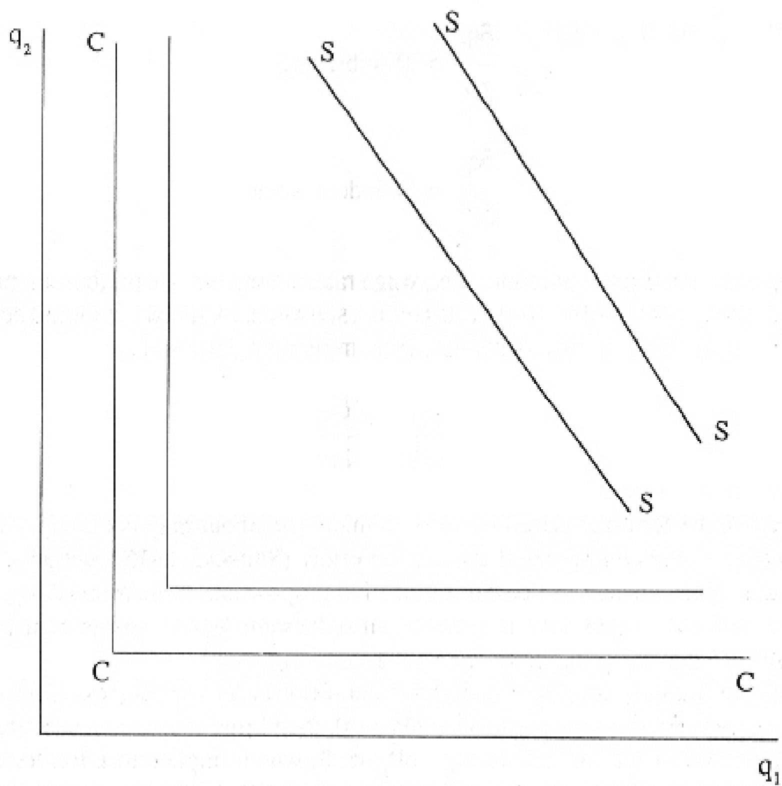

Figure 1

If the marginal productivity of fertilizers is increased by the use of family labour, fertilizer and family labour are complements. On the other hand, if the marginal productivity of fertilizer is decreased with increased use of manures, fertilizer and manure are substitutes. When perfect Fisherian complementarity holds, a rise in the price of the i^{th} input must reduce the demand for the j^{th} input.

$$\frac{\delta q_i}{\delta P_i} < 0$$

Perfect substitutes are defined in price terms. A rise in P_i (price of input i) will increase q_j (quantity of input j) for a substitute.

$$\frac{\delta q_i}{\delta P_j} < 0 \text{ complement}$$

$$\frac{\delta q_i}{\delta P_j} > 0 \text{ substitute}$$

$$\frac{\delta q_i}{\delta P_j} = 0 \text{ independent}$$

If increase in the price of labour, i.e., wage rate, causes, ceteris paribus an increase in the demand for fertilizer then fertilizer is a substitute for labour. It should be noted that because this is a gross-substitute or complement definition,

$$\frac{\delta q_i}{\delta P_j} \neq \frac{\delta q_j}{\delta P_i} \tag{2.2}$$

i.e., when the fertilizer price increases, demand for labour may not go up. Another definition is the compensated cross-price effect [Slutsky, (1915)] obtained when output is held constant in a cost minimization proposition. If the price of input falls output will rise, and in order to keep output at the same level output price may have to fall. We thus keep the producer on the same isoquant.[5]

Sometimes the uncompensated price definition is denoted as gross substitute or gross complement criterion. If $\delta q_1 / \delta P_2 > 0$, then hired labour is a substitute for fertilizer and at the same time $\delta q_2 / \delta P_1 < 0$, which implies that fertilizer is a complement to labour. This kind of contradiction is likely because uncompensated price effects are not symmetric and single equation estimation does not guarantee symmetry, even if profit maximization is adopted.

5 There are three definitions of substitutes and complements for derived demand under three alternative concepts: (a) constant output, (b) constant cost, and (c) constant marginal cost. In the theory of derived demand for factors of production. Allen-elasticity of substitution is first obtained, from it, cross-price elasticities of demand are derived. Allen elasticities of substitution are obtained when cost is minimized subject to exogenously given output, and this corresponds to compensated price definition. Usually duality theroy is adopted for Allen elasticity of substitution.

As there are only two prices available, i.e., fertilizer and hired labour, and profits are maximized subject to a given technology, the discussion can be confined to uncompensated cross partial-derivative. Other propositions on the production theory may be useful here. The demand for each input is negatively sloped with respect to own price

$$\frac{\delta FQA}{\delta FPRICE} < 0 \qquad (2.3)$$

i.e., when fertilizer demand (FQA) is estimated the demand is downward sloping with respect to fertilizer price. Also

$$\frac{\delta Yield}{\delta Price} > 0 \qquad (2.4)$$

which implies that the partial derivative of output with respect to output price must be positive. Since we do not have price data on different crops for each farmer, this cannot be attempted in a cross-section framework.

$$\frac{\delta FQA}{\delta Price} = \frac{-\delta Yield}{\delta FPRICE} < 0 \qquad (2.5)$$

If an increase in output price leads to a decline in input (FQA), then it is an inferior input. This can happen with family labour because farmers may prefer leisure to extra work. If output increases when the fertilizer price increases, then it is an inferior input. No conclusion can be reached on this since we do not have output prices oand input prices for all the inputs.

Section-III

Fertilizer Consumption Relationships

In this section, the fertilizer consumption equations are estimated using cross-section data. Farmers who do not buy fertilizer are eliminated. This is because the farmers who do not buy fertilizer are non-adopters as far as the HYV crop is concerned.[6] The HYV adoption is one of the most important factors causing

[6] All non-using households are observed to fall within the category of mean farm size below 1.92 acres. There are 51 non-users, of whom 50 are non-adopters of HYV. The productivity of non-used land is 21 per cent less when the average value of output per acre in users and non-users sample farm households is compared. Their land is not irrigated and no HYV has spread to their land. Non-users come largely from flood plain and saline soil areas.

increased use of fertilizer. Non-adopters are located in villages where irrigation facilities are poor. Adoption decision is largely explained by the availability of irrigation, institutional and non-institutional credit. In the fertilizer consumption equation, proportion of HYV area is used, and this refers only to adopters. It can be stated that farmers who do not use fertilizer live in the flood plain and the saline soil areas. It is not the houeshold characteristics, but geographical/environmental factors which are responsible for non-adoption of HYV. When technological change occurs, the demand for fertilizer may tend to rise with the adoption of high yielding variety. The increased fertilizer demand can have a significant impact on labour demand and wage rates. Parikh (1985) found that fertilizer and family labour were substitutes, while the elasticity of fertilizer demand with respect to wage rate was 0.3251when the yield effect was held constant. On a cross-section data, it was difficult to analyse the implications of HYV adoption and because of limited variations in prices of inputs, it was not possible to estimate price elasticity of demand for different inputs. Technical change in developing agriculture can be classified into two broad categories: (a) biological and (b) mechanical. Biological innovations usually refer to factors that raise land productivity. Better seeds and the use of organic fertilizer in appropriate doses at the right time are useful ingredients of the green revolution. When the green revolution comprises biological innovations, more jobs can be created.[7] In the case of Indian Punjab, Sidhu (1974) and Johl (1975) have shown that a rise in the demand for labour causes an increase in real wages. Evidence exists to confirm the net inflow of agricultural labour, particularly during the sowing and the harvesting seasons from the neighbouring provinces like Uttar Pardesh and Rajasthan. On the contrary, in other provinces of India where green revolution did not come about through biological innvoations, real wages remained static or registered a fall.

Test of Hypotheses

Various hypotheses are put to test:

1) Are fertilizer and labour and fertilizer and manure complements or substitutes in Fisher's sense?
2) When the wage rate is used in the fertilizer equation, are fertilizer and labour substitutes in an uncompensated sense?

[7] In a land scarce economy, yield increasing and land saving inputs such as fertilizer, irrigation and HYVs are substituted for land. The change in relative scarcities of resources especially land and labour induce a derived demand for technological innovations to facilitate the substitution of relatively less scarce and cheap factors for more scarce and expensive ones. This is the theory of induced technical and institutional change [Binswanger and Ruttan, (1978)].

3) Are fertilizer and hired labour substitutes? Is family labour a substitute in Fisher's sense? Is there any relationship between holding size and fertilizer use per acre?

Table 3 estimates relationships between fertilizer use per cropped acre and inputs per cropped acre along with structural variables such as cropping intensity, infrastructure and technological variables such as High Yielding Variety area. In Table 4 similar regression results are presented using fertilizer per acre of cropped area, but including non-users of fertilizer in the sample, using single equation OLS and Tobit procedures.

Equation (1) in Table 3 and equations (1)and (2) in Table 4 test whether fertilizer and labour are substitutes or complements. In the first equation (Table 3) Fisher's definition is used. Both forms of labour, namely family and hired labour are complements to fertilizer use. This definition produces only polar cases, as mentioned before, and most economists would regard it as a non-economic definition. Using the price definition, we find that labour and fertilizer are substitutes. The coefficient with respect to wages per work day is positive and significant. Since there are only two variable inputs in these partial equilibrium type regression equations,[8] we might get contradictions. If wages per work day was considered as a cash constraint for farmers who are tenants-cum-sharecroppers, it may indicate the role of a liquidity constraint. In equation (3), Table 3 we keep the basic variables of equation (2) and add family labour and size of the holding as variables. It is confirmed that family labour turns out to be a complement to fertilizer in cropped area relationship directly, while if family labour has a price, it turns out to be a substitute [Equation (2) in Table 3]. Size of the holding plays an unimportant role in fertilizer use. In all the regressions, manure and fertilizer are complementary inputs.

Coefficients on infrastructure and the high yielding variety area are highly significant in the regressions presented here. The coefficient on the cropping intensity index has the correct sign, and is statistically significant in all the regressions where cropped area is used as an explanatory variable. On the substitutability/ complementarity issue, it can be concluded at this stage that the absence of data on prices of any other input (other than two) is an impediment to an appropriate specification and the economic testing of the hypothesis.

[8] There is a shadow price for family labour, but with one year data, it is not possible to estimate it. In this analysis, we are making alternative assumptions that in equation (2), Table 3, family labour and hired labour combined are treated as variable inputs, while in equations (3) and (4), (Table 3) family labour is a given input, while hired labour is a variable input.

[9] All these are single equations, and joint estimation of the input demand functions with the production function is not attempted. This is because more than two inputs cannot be treated as variables as the price data are not available for the other inputs.

TABLE 3

Fertilizer per Cropped Acre: OLS
Regression Coefficients, t-Ratios, R^2 and SEE

Fertilizer Consumption	Cons-tant	FPRICE	WAGE	FLA	HLA	DINF	CROPIN	MNRA	HYVA	A	R^2/SEE	F/n
1.	78.1268 (7.463)	-13.4256 (4.999)		0.0895 (0.995)	0.8109 (5.636)	-4.3456 (8.021)	0.3637 (0.585)	0.0877 (2.304)	118.76 (16.882)		0.6431 34.908	103.493 412
2.	98.1416 (8.721)	-17.7648 (5.639)	0.3486 (4.167)			-4.0912 (7.659)	0.1404 (0.230)	0.1469 (3.635)	128.948 (19.274)		0.6468 34.421	110.785 370
3.	100.815 (8.851)	-17.8155 (5.686)	0.3442 (4.124)	0.1978 (2.191)		-3.7713 (6.834)	-0.4196 (0.463)	0.1605 (3.913)	132.033 (19.405)	0.3533 (0.588)	0.6528 34.221	84.845 370
4.	101.721 (9.022)	-17.766 (5.678)	0.3405 (4.095)	-0.2117 (2.434)		-3.7443 (6.815)	-0.0247 (0.041)	0.1632 (4.009)	131.4434 (19.549)		0.6525 34.190	97.092 370

Note:
The number of observations is different between equation (1) and the others because if wage costs were not recorded, wage per worker turns out to be zero, so those observations were eliminated.
Figures in parentheses below the coefficients are t-ratios.

TABLE 4

Fertilizer per Cropped Area
Tobit and OLS Estimated Regression Coefficients, Standard Error of Estimate

Name of the Dependent Variable	Constant	DINF	CCB	FPRICE	WAGE	FLA	HYVA	HLA	A	MNRA	Method of Estimation	R^2/SEE	F/n	σ/t(σ)
FQA	90.4831	-4.1469	0.2336	-14.3035	0.3459	-0.0873	141.178				OLS	0.6535	141.46	
(1)	(9.472)	(8.332)	(0.384)	(5.390)	(4.112)	(1.263)	(23.374)					(34.678)	457	
FQA	83.6738	-4.4726	0.5932	-13.785	0.3484	-0.0402	149.65				TOBIT		Log L=	36.7706
(2)	(9.603)	(7.565)	(0.435)	(6.524)	(2.834)	(0.679)	(28.180)						-2105.0	(34.415)
FQA	76.3168	-4.6143	0.5642	-13.1397		0.16839	126.313	0.7748			OLS	0.6665	149.88	
(3)	(7.714)	(9.412)	(0.941)	(5.033)		(2.075)	(19.315)	(5.922)				34.0227	457	
FQA	68.4933	-4.9488	0.9338	-12.5643		0.2268	133.919	0.8159			TOBIT		Log L =	36.0298
(4)	(7.442)	(8.204)	(0.535)	(6.059)		(3.040)	(22.043)	(6.849)					-2096.3	(34.399)
FQA	75.5521	-4.6365	0.0633	-13.2023		0.1812	126.815	0.7680	0.4355		TOBIT	0.6669	128.45	
(5)	(7.598)	(9.438)	(0.073)	(5.052)		(2.189)	(19.293)	(5.8540)	(0.790)			(34.0369)	457	
FQA	66.8842	-4.9953	-0.0594	-12.6826		0.2524	135.067	0.8018	0.8689				Log L=	35.9896
(6)	(7.336)	(8.274)	(0.035)	(6.130)		(3.330)	(22.074)	(6.280)	(1.074)				-2095.2	(34.554)
FQA	75.0275	-4.4658	0.5544	-13.2428		0.1471	126.140	0.7677		0.0352	OLS	0.6681	129.104	
(7)	(7.564)	(8.932)	(0.926)	(5.077)		(1.786)	(19.310)	(5.871)		(1.467)		(33.979)	457	
FQA	67.2490	-4.8036	0.9261	-12.6699		0.2063	133.704	0.8081		0.0349	TOBIT		Log L=	35.0276
(8)	(7.442)	(8.204)	(0.535)	(6.059)		(3.040)	(22.043)	(6.849)		(2.230)			-2095.4	(34.492)

Note:
Four observations are lost because cropped area was greater than zero and net sown area was zero. Since we suspect that these are computational or transfer errors, we eliminated those observations.
Figures in parentheses below the coefficients are the t-ratios.

The fertilizer price elasticity at mean values of fertilizer [Table 3, equation (1)] input and fertilizer price turns out to be -0.7082 from the first regression. All these estimates are very close. Differences due to misspecification arise and a simultaneous equation bias cannot be eliminated, i.e., input demand and output may be due to joint endogenous decisions. With one year data, this cannot be resolved in any satisfactory manner. Moreover family labour will have a price (shadow) and as this is not avilable, we have a missing variable bias.

The value of output per cropped acre was estimated with interaction between inputs and quadratic terms of inputs. The purpose was to use the Pareto-Georgescu-Roegen definition: to what extent is the marginal productivity of fertilizer increased or decreased by using family labour, hired labour and manure? We found that the coefficient on HLA x FQA, FLA x FQA and MNRA x FQA were statistically significant, but because quite a few other coefficients were not significant in a quadratic regression, it was decided to drop the insignificant interaction and quadratic terms. The re-estimated equation is presented below:

$$\underset{}{VVADJA_i} = \underset{(8.504)}{2806.35} + \underset{(0.230)}{2.9915HLA_i} - \underset{(0.468)}{3.0517FLA_i} - \underset{(1.778)}{8.4714FQA_i}$$

$$- \underset{(2.588)}{15.5765MNRA_i} + \underset{(2.768)}{1111.78HYVA_i} - \underset{(0.\ 268)}{6.7175DINF_i}$$

$$- \underset{(3.453)}{0.0963\ (FQA_i)^2} - \underset{(2.377)}{0.0462(MNRA_i)^2} - \underset{(0.869)}{0.2159\ (HLAxFLA)_i}$$

$$+ \underset{(4.746)}{0.4371(HLAxFQA)_i} + \underset{(6.41)}{0.4542(FLAxFQA)_i}$$

$$+ \underset{(2.764)}{0.0826(MNRAxFQA)_i} \qquad (3.1)$$

$$R^2 = 0.5187 \qquad SEE = 1386.76$$
$$F = 31.7997 \qquad n = 367$$

The last three terms of the equation are positive and statistically significant. These indicate that marginal productivity of fertilizer is increased by the availability or use of family labour, hired labour and manures, implying that fertilizer is a complement to family labour, hired labour and manure. These results support probably the use of log quadratic or generalized Leontief production function. They provide evidence in favour of complementarity of fertilizer to family labour, hired labour and manure, which is consistent with a priori beliefs about Bangladesh agriculture.

The results based on all the three definitions are presented in Table 5.

TABLE 5

Complements and Substitutes using Three Definitions

Name of Input Pair	Fisher Definition	Pareto-Georgescu-Roegen Definition	Uncompensated Price Definition
Fertilizer/Manures	Complements	Complements	---
Fertilizer/Hired Labour	Complements	Complements	Substitutes
Fertilizer/Family Labour	Complements	Complements	Substitutes
Manures/Hired Labour	Not Analysed	Independent	---
Manures/FamilyLabour	Not Analysed	Independent	---
Hired Labour/Family Labour	Not Analysed	Independent	---

Note: Uncompensated price definition and compensated price definition are the same when profit maximisation is adopted since income effect of demand theory is not relevant in production theory under the goal of profit maximization.

Section IV

Summary

In this paper, we have shown that the marginal value product of an input divided by the input price yields the allocative ratio. The ratio is derived both at a disaggregate level using yield per acre by crops and value of cropped output per acre at an aggregate level. Both these relationships are linear, and tend to yield results which are consistent between weighted micro and macro allocative ratio. The allocative ratio for fertilizer is 2.21, for hired labour 1.24, and for family labour 0.96 per taka investment in each of these inputs. Different ways of devising allocative ratio alter the magnitudes slightly, but the ordinal ranking remains the same. For a policy maker, there seems to be some justification for inducing farmers to use more fertilizer through price incentives on credit. If fertilizer and labour are complementary inputs, this will also lead to an increase in the use of hired labour and family labour . If fertilizer and hired labour are substitutes, then an increase in fertilizer price will lead to a reduction in the demand for hired labour. The issue of substitutes and complements is more complicated and despite different definitions available in the literature, a straightforward compensated cross-price derivative definition is not applicable because of a large number of unobserved prices for inputs, price of crop output and at times heterogeneous non-purchased inputs such as irrigation, manure and family labour. This raises the issue that price definition of substitutes and complements may not be useful in an economy where inputs are not sold in the factor market. Unfortunately, no other definition other than the original Fisherian polar case definition can be applied in some situations, and this tends to indicate that all types of labour and fertilizer are complements. On the other hand, when hired labour has a market price, we find that both hired labour and fertilizer and family labour and fertilizer turn out to be substitutes.

In a densely populated country, (given the problem of unemployment), the complementarity of new inputs with traditional inputs, under yield increasing technological change will favour the adoption of high yielding variety. For a country like Bangladesh, the adoption of HYV should not lead to substitution of labour by new inputs such as fertilizer, and if fertilizer and labour are complementary, increase in yield due to adoption of HYV inputs will not cause increase in unemployment of surplus labour. To some extent, this will reduce migration to urban areas and contribute to improvements in living standards. Such a technological change in Bangladesh must be very welcome given that millions of people are below poverty and nutrition requirement levels.

References

Binswanger, H.P., and V.W. Ruttan, 1978, Induced innovation technology, Institutions and development, Baltimore: Johns Hopkins University Press.

Fisher, I., 1892, Mathematical investigations in the theory of value and prices, Reproduction in 1925, New Haven: Yale University Press.

Johl, S.S., 1975, Gains of the green revolution: How they have been shared in Punjab, Journal of Development Studies, 11(3).

Pareto, V., 1909, Manuel d'economie politique, Paris: V. Grand and E. Briere.

Parikh, A., 1985, Some aspects of employment in Indian Agriculture, World Development, 13(6).

Parikh, A., 1990, The economics of fertilizer use in developing countries: A case study of Bangladesh, Hampshire: Gower Publishers.

Samuelson, P.A., 1974, Complementarity – An essay on the 40th anniversary of the Hicks-Allen revolution in demand theory, 12(4)

Sen, A.K., 1975, Employment, technology and development, Oxford: Clarendon Press.

Sidhu, S., 1974, Relative efficiency in wheat production in the Indian Punjab, American Economic Review, 64(4).

Slutsky, E., 1915, Sulla teoria del bilancio del consumatore, Gior, Degli Economics, Translated in English, 1952, On the theory of the budget of the consumer, in: G.J. Stigler and K.E. Boulding (eds.), Readings in price theory, Chicago: Richard D. Irwin.

Stiglitz, J.E., 1969, Rural-urban migration, surplus labour and the relationship between urban and rural wages, Eastern Africa Economic Review, 1(2).

Mean and Variance of Variables Used

	Name of the Variable	Mean	Standard Deviation
11.	Infrastructure Index (DINF)	7.3407	3.4510
12.	Cropping Index (CROPIN) (CCB)	1.7870	2.7053
13.	Fertilizer Price per Seer (FPRICE)	3.1894	0.6192
14.	Wage per Work Day in Taka (WAGE)	18.344	19.4240
15.	Family Labour in Days per Acre (FLA)	35.5240	25.5050
16.	High Yeilding Variety Area Proportions (HYVA)	0.3001	0.2876
17.	Hired Labour per Acre (HLA)	19.3860	15.1570
18.	Cropped Land in Acres (A)	3.5526	4.4457
19.	Fertilizer per Acre in Seers (FQA)	60.4590	58.5240
10.	Value of Fertilizer per Acre (Takas) (FVA)	181.7800	178.2500
11.	Values of Manures per Acre (Takas) (MNRA)	42.1600	68.8600
12	Adjusted Value of Output (Takas) (VVADJA)	3211.0400	1914.0600
13.	Bullock Costs per Acre (Takas) (BLA)	36.278	72.610

Note: Variables with suffix 'A' refer to cropped acre.