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Efficiency Differentials in Irrigated Rice Farming in Bangladesh: A Test on Neutrality

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Efficiency Differentials in Irrigated Rice Farming in Bangladesh: A Test of Neutrality.¹

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Abstract:

In this paper an attempt is made to test the neutrality of improved management technology of irrigated rice farming between socio-economic groups of irrigated farmers in terms of technical efficiency. Analysis of Covariance models are used to test the hypothesis that the production functions for irrigated rice across farmers' groups are homogeneous. A number of production functions were estimated for different groups of farmers by stratifying data according to farm-size, tenancy, and farm location. The results are consistent with the view that the production functions are often not homogenous across the different groups of farmers.

Introduction

The modern seed-fertiliser technology has a clear comparative advantage relative to traditional technology only in the areas which are 'properly' irrigated (Hsieh and Ruttan, 1967; and Wickham et al., 1978). The positive impact of irrigation development on land productivity, generation of employment and income and on economic growth is well documented in the literature (Hayami and Ruttan, 1971; Haque, 1975; and Hayami and Kikuchi, 1978). However, a common observation in most of the developing countries is that the modern technology is used much below potential at farm level, and consequently, the benefits to the farmers have been below expectations.

There is also dispute regarding the distribution of benefits from new technology (Lipton 1978). Critics have claimed that the new technology has led to a widening of existing disparities in income distribution (Grabowski 1979 and Dasgupta 1979). On the other hand, it has been argued that the technology is scale neutral, provided that there is equal access to inputs for all farmers. A number of studies have examined the accessibility of inputs, especially of seeds, fertilisers, chemicals and credit in the context of the new technology (Schluter and Mellor, 1972; Hossain, 1977; Alauddin and Tisdale, 1991). Although the adoption rate of seed-fertiliser technology is relatively high in areas under irrigation, in the literature it is suggested that even in areas under irrigation the adoption rate is low and that the distribution of benefits is unequal because of the 'technological externality' and 'institutional uncertainty' inherent in the irrigated environment (Bromley, 1982). These two phenomena induce farmers in developing countries to allocate resources cautiously, or to adopt 'cautious optimising behaviour' (Bromley, 1982). A little elaboration of these concepts may help in understanding why farmers in developing countries adopt new technology below its potential.

Technological externality arises in the irrigation environment because the use of water and other resources are essentially physical activities and farmers are linked with the physical conveyance system and this link

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introduces interdependence among farm units. In the production process, whenever the output of a farm depends not only on the factors of production utilised by that farm but also on the output and factor utilisation of another farm or a group of farms, technological externality exists (Scitovsky, 1954)³. Under such an environment the market mechanism fails to reap the benefit of new technology to its full potential. Therefore, it is suggested that the development of appropriate 'institutions' is necessary for effective utilisation and adoption of new technologies (Bromley, 1977; Carruthers, 1983; Sagordoy et al., 1982).

Here, institutions are defined as the indispensable rules and conventions with the aid of which a social and economic system operates (Schultz, 1968). Property rights are the essence of the predictability in these rules and conventions. When these rules and conventions are either ignored or selectively followed or changed in an arbitrary manner the best plans of entrepreneurs are confounded and such circumstances give rise to a situation beset by institutional uncertainties. As farmers adoptive behaviour is based upon their feedback from their prior experience they are unwilling to adopt more productive agricultural practices when they experience institutional uncertainty in an irrigation system. Hence farmers may not adopt more productive agricultural practices because of their possible or likely inability to get irrigation water when the crop needs it most.

Where there is a lack of effective institutions, farmers with economic and social power have an incentive to exercise their influence on the scheme's management to increase the quantity of water supplied to them at the expense of less powerful farmers (Islam, 1987; and Islam and Quilkey, 1987). The arbitrary exercise of power increases the uncertainty of the less powerful who may be induced as a result to reduce the commitment of resources including land to irrigate even where, under free market conditions, such commitment would be privately and socially beneficial.

The failure of the new technology to achieve its full potential has led to the recognition that its success in increasing output depends not only on a high rate of adoption induced by cheap inputs, but also on the efficient application of the new technology at farm level through significant improvement in water use by the establishment of effective institutions (Bromley, et al., 1977; Carruthers, 1983; Shapiro 1983). A major goal of this institutional change is the provision of improved management giving appropriate weights to elements such as: construction, operation and maintenance of water ways and pumping equipment; input supply (timely and adequate quantities), agricultural extension, credit facilities, marketing, farmer organisations, lines of communication between water users and their organisations, as well as liaison between these organisations and public departments and institutions which accommodate financial planning and fund raising, including the collection of user charges. The main purpose of institutional change is to create incentives for farmers, whose land has potential for inclusion in an irrigation scheme, to apply new technology most effectively.

In this paper, following the approach used by Shand and Kalirajan (1986), an attempt has been made to determine whether technological externalities are removed by the introduction of appropriate institutions in irrigated agriculture in a developing country. The objectives are to test in terms of technical efficiency, the neutrality of improved management technology on irrigated rice farming, introduced by institutional changes, between locations, and socio-economic groups of farmers. The question addressed is essentially whether or not the implementation of new technology has resulted, ex post, in a uniform improvement in the productive performance of farmers as a result of the scheme.

The Data

The IDA Deep Tubewell Project in the North-East region of Bangladesh, was a major small-scale irrigation scheme development project financed by the World Bank, the British Government and the Government of Bangladesh in early 1983 and completed in 1992. The project was designed to install 4,000 deep tubewells (DTWs) phase by phase over 10 years. On average each DTW with 2 cusec discharge capacity, was

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'Technological externality' is distinct from 'pecuniary externality' in terms of the interdependence of economic agents. In the former concept economic agents are physically independent whereas in the latter concept they are interdependent in the input-output market (Schmid, 1978).

designed to irrigate 25 hectares of land to enable irrigated rice cropping in the dry season; increase cropping intensity and achieve a substantial increase in rice yields, based on the farmers' adoption of high-yielding rice varieties, and improved water management technology; strengthening farmers' two-tier cooperative system⁴ and ensuring farmers access to essential inputs and credits. A comprehensive analysis, presented in the Final Report (MMI, 1992) of the project claimed that its major objectives had largely been achieved in 1992.

Data were collected as a part of the annual monitoring survey in 1989-90 irrigation season, at a time when the project was considered to have reached the stage of maturity when the full range and extent of benefits were expected to be available to farmers within the command area of the project. In this study the analysis to test the uniformity of 'success' of the IDA Deep Tubewell Project, was conducted with these data derived from the Project from a stratified random sample of farm plots (parcels) within randomly selected DTW's. The sample plots were stratified according to ownership categories such as, farm-size and tenancy, and distance of the sample plot from the water pump. The following is the distribution of sample plots according to the above stratification :

	Sample Size
1. Distance of a plot from the pump:	
a) Close Distance (< 200 metres)	221
b) Middle Distance (201 to 500 metres)	162
c) Far-distance (> 500 metres)	51
2. Tenure status of the sample plot:	
a) Owner operated	397
b) Tenant operated	37
3. Operational farm-size of the sample plot:	
a) Smallest farm-size (< 1.50 acres)	147
b) Small farm-size (1.51 - 2.50 acres)	86
c) Medium farm-size (2.51 -5.00 acres)	133
d) Large farm-size (> 5.00 acres)	68

Production function analysis is applied both to the whole sample, and separately to the samples of plots cultivated under different farm-size, tenancy and distance within the command area.

The following transcendental production function was selected for the present study:

$$Y = A \prod X_i^{\beta_i} \exp (\Sigma \gamma_i X_i) \quad (1)$$

Where Y is output and the X_i 's are inputs.

From the viewpoint of production economics, this functional form incorporates all the three stages of the production process proposed in neo-classical theory. The mathematical properties of this functional form is presented in Table 1. The algebraic values of β and γ estimated from the model (1) explain the three stages of production. Of these, the most important and interesting cases of the production process occur when the estimated value of γ is negative, and at the same time, the modulus of β is greater than one. In this context,

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This two-tier cooperative system was developed by the Bangladesh Academy for Rural Development, Comilla, Bangladesh.

Table: 1 The Properties of the Transcendental Production Function (Adapted from Halter et al. 1957).

Values of γ	Values of β	$Y = \alpha X^\beta e^{\gamma X}$
$\gamma < 0$	$0 < \beta \leq 1$	Increases at a decreasing rate until $X = -\beta/\gamma$, then decreases.
	$\beta > 1$	Increases at an increasing rate until $X = \frac{-\beta + \sqrt{\beta}}{\gamma}$, then increases at a decreasing rate until $X = -\beta/\gamma$, then decreases
	$\beta < 0$	Decreases at a decreasing rate
$\gamma = 0^*$	$0 < \beta < 1$	Increases at a decreasing rate
	$\beta = 1$	Increases at a constant rate
	$\beta > 1$	Increases at an increasing rate
$\gamma > 0$	$0 < \beta < 1$	Increases at a decreasing rate until $X = \frac{-\beta + \sqrt{\beta}}{\gamma}$, then increases at an increasing rate
	$\beta \geq 1$	Increases at an increasing rate
	$\beta < 0$	Decreases at a decreasing rate until $X = -\beta/\gamma$, then increases

* When $\gamma = 0$, this function is the Cobb-Douglas production function.

output first grows at an increasing rate until value of the input, $X = \frac{-\beta + \sqrt{\beta}}{\gamma}$. It then grows at a

decreasing rate, until $X = \frac{-\beta}{\gamma}$, and finally it decreases. When each γ_i in the above model (1) turns out to be zero, the transcendental function becomes the standard Cobb-Douglas function.

The following variables were selected for the present study; where the empirical production function was of the form

$$Y = \alpha \prod_i X_i^{\beta_i} \exp(\sum \gamma_i X_i + \sum \alpha_i D_i + U) \quad (2)$$

Y	=	total paddy (rough rice) output per sample irrigated plot in maunds (1 maund = 37.38 kg).
X_1	=	area of the sample irrigated plot in 0.01 acre.
X_2	=	nitrogenous fertiliser applied per sample irrigated plot in kg.
X_3	=	family labour utilised in paddy production per sample irrigated plot in man-days.
X_4	=	hired labour utilised in paddy production per sample irrigated plot in man-days ⁵ .
U	=	the random error term.
D_i	=	groups specific dummies, where i stands for number of dummies.

This transcendental functional form was applied by Desai (1973) in Indian Agriculture and by Shand and Kalirajan (1986) in Malaysian Agriculture. In their empirical model these two researchers used whole-year aggregated farm household data and investigated differences in production functions between and within developed and less developed agricultural regions. Desai (1973) in his study, has used gross value of production of all crops grown on a farm in a year as dependent variable and has used net sown area, total annual expenditure on plant nutrients, irrigation water, hired labour, all other inputs (such as seeds pesticides, bullock labour, repair and maintenance etc.) and number of family labours working on farm as independent variables. Shand and Kalirajan (1986) have used quantity of annual paddy production per farm as dependent variable and in physical units, paddy operational area, chemical fertiliser and total labour as independent variables.

In our view, such annual aggregate farm level data conceal inter- and intra-seasonal variations of productivity within and between farming groups. We believe that the effect of improved management on the technical efficiency of production function is better evaluated from a set of data which is collected from randomly selected pieces of land in an irrigation season. In this study, the differences in production function is tested between sample groups within the IDA DTW project.

Analysis of the Results

With the introduction of a new management technology for irrigated paddy production in the IDA DTW project where farmers are assured of equal access to essential inputs, including water and credit, it is hypothesised that the production functions across the sample group within the project area will be homogeneous.

To conduct the covariance analysis, it was necessary to estimate twenty five production functions (See

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Family labour and hired labour are considered as separate variables considering differences in terms of quality and effort (see Stiglitz, 1974; and Binzwinger and Rosenzweig, 1986).

Appendix Tables A-1 to A-7). Using the OLS estimates of the production functions, a series of statistical tests were conducted to examine the relationships (See Appendix Tables A-8 and A-9).

Test of differentials: The test of neutrality of improved management technology is carried out in three steps. Firstly, a statistical test has been conducted to determine whether improved management practices brought about homogeneity in production functions across the sample groups located at different distances from the water source within the command area of the project. In an irrigation environment, as the allocation of resources (such as seed, fertiliser, labour and other inputs) by the farmer is induced by the farmer's expectation about water availability on time and in adequate quantity, it is commonly observed that because of the inherent technological externalities, reliability of water supply to an area is negatively related to its distance from the water source thereby inducing farmers, belonging to different physical and socio-economic classes, to allocate resources cautiously and operate on different production functions. This analysis is carried out to investigate whether in the IDA DTW II project such externalities were removed by the implementation and transfer of improved management technology to farmers.

The tests applied show that the production functions are clearly not homogeneous overall for farm plots located at different distances (Table 2) from the water source. However, the intercepts for middle-distance and far-distance plots are not significantly different. This indicates that the performance of middle and far-distance plots, in terms of technical efficiency are the same. But the intercepts between close and middle, and close and far-distance plots are significantly different. The values of the intercept coefficients (Table 3) indicate that farm plots located close to the water source are technically more efficient. This test result also indicates that there is an inverse relationship between distance of farm plots from the water source and technical efficiency.

In terms of differences in the slopes of the production functions only close and middle distance plots are homogeneous. This result suggests that despite improved management practices production functions across the distance groups are significantly different.

The second step is to find whether the production functions are different between owner and tenant operated plots. The tests applied show that, the production functions are significantly different both in intercept and overall (Table 2). However, in terms of slopes, the functions are homogeneous. In terms of technical efficiency the tenant operators appeared to be more efficient (Table 4). If one is interested in the distribution of benefits it is interesting to note that the majority of the irrigated sample plots were operated by the owner-farmers.

Thirdly, an attempt has been made to test whether the improved management technology is scale neutral. The results show that overall, smallest and small farm-size groups operate on the same production function. However in terms of technical efficiency they are significantly different (Table 5). The values of the intercepts show that the smallest farm-size groups are technically more efficient.

Comparison between small and medium farm-size groups shows that in all respect they operate on different production functions. In terms of technical efficiency small farm-size groups are more efficient than medium size groups. However for medium and large farm-size groups, their technical efficiency is not significantly different but overall and slope-wise they operate on different production functions (Tables 2 and 5). It is interesting to note that the values of intercepts consistently decrease with the increases in farm-size. From this result one can argue that, in the IDA DTW project smaller farm-size groups are technically more efficient in operating irrigated plots.

Marginal Analysis: The above analysis of tests of neutrality of improved management technology indicates that all sample groups operate on different production functions. Therefore, for marginal analysis to examine the productivity of resources, production functions for each individual sample group which have been estimated are used separately. The regression results of these selected production functions for each of these groups along with the results of the pooled model are given in Tables 3, 4 and 5.

Table: 2 Test of Differentials in Production Functions

Test Characteristics	<u>Intercept</u> F-Values	DF.	<u>Slope</u> F-Values	DF.	<u>Overall</u> F-Values	DF.
<u>Plot Distance from Pump:</u>						
Close Vs. Middle	16.334*	(1,373)	0.561	(8,365)	2.296*	(9,365)
Middle Vs. Far	0.157	(1,103)	2.302*	(8,95)	2.065*	(9,95)
Close Vs. Far	4.176*	(1,262)	2.869*	(8,256)	3.041*	(9,256)
<u>Plot Ownership:</u>						
Owner Vs. Tenant	12.527*	(1,424)	1.748	(8,416)	2.956*	(9,424)
<u>Farm-size:</u>						
Smallest Vs. Small	4.859*	(1,223)	0.371	(8,215)	0.858	(9,215)
Small vs. Medium	-11.880*	(1,227)	12.331*	(8,269)	9.209*	(9,269)
Medium Vs. Large	0.204	(1,191)	-2.605*	(8,183)	-20.333*	(9,183)

* Significant at 5% level.

Table: 3 OLS Estimates of Transcendental Production Function Models for Samples from Different Distances from Water Source.

Variables	Parameters	Close Distance		Middle Distance		Far Distance	
		Coefficients	Standard Errors	Coefficients	Standard Errors	Coefficients	Standard Error
Intercept	α	-0.072*	0.252	-0.577	0.446	-1.333*	0.829
Plot Area (in 0.01 acre)	β_1	0.799*	0.150	0.362*	0.224	1.400*	0.411
	γ_1	-0.002	0.004	0.008	0.008	-0.021*	0.008
Fertilizer (kg.)	β_2	-0.014	0.087	0.262	0.169	0.011	0.337
	γ_2	0.003	0.002	-0.005	0.006	-0.007	0.011
Family labour (in man-days)	β_3	0.037*	0.064	0.073	0.075	0.078	0.086
	γ_3	-0.008	0.008	0.003	0.010	0.005	0.023
Hired Labour (in man-days)	β_4	0.179*	0.070	0.271*	0.103	-0.355	0.224
	γ_4	-0.001	0.004	-0.004	0.007	0.041*	0.020
Number of Observations			221		162		51
R^2			0.77		0.64		0.56
\bar{R}^2			0.77		0.62		0.48
F-Statistics			92.77		33.29		6.72
Degrees of Freedom			(8,212)		(8,153)		(8,42)

* Significant at 1% level.

Significant at 5% level.

+ Significant at 10% level.

Table: 4 OLS Estimates of Transcendental Production Function Models for Sample under Different Tenure Status.

Variables	Parameters	All Sample Groups		Owner Operated		Tenant Operated	
		Coefficients	Standard Errors	Coefficients	Standard Errors	Coefficients	Standard Error
Intercept	α	..	..	-0.928*	0.212	1.081	1.178
Tenancy Dummy-1	α_1	-0.718*	0.213	..	..	..	..
Tenancy Dummy-2	α_2	-0.955*	0.222	..	..	..	..
Plot Area (in 0.01 acre)	β_1	0.876*	0.117	0.984*	0.117	-0.241	0.699
	γ_1	-0.007*	0.003	-0.010*	0.003	0.029	0.024
Fertilizer (kg.)	β_2	-0.041	0.077	-0.022	0.077	0.123	0.434
	γ_2	0.004*	0.002	0.003	0.002	0.002	0.009
Family Labour (in man-days)	β_3	0.104*	0.047	0.106*	0.047	-0.070	0.278
	γ_3	-0.0007	0.006	-0.001	0.006	0.013	0.049
Hired Labour (in man-days)	β_4	0.091*	0.055	0.032	0.057	0.323	0.236
	γ_4	0.006*	0.004	0.009*	0.003	-0.015	0.023
Number of Observations			434		397		37
R^2			0.98		0.70		0.62
\bar{R}^2			0.98		0.70		0.51
F-Statistics			1942.57		115.73		5.73
Degrees of Freedom			(10,424)		(8,388)		(8,28)

* Significant at 1% level.

Significant at 5% level.

+ Significant at 10% level.

Table: 5 OLS Estimates of Transcendental Production Function Models for Different Farm-size Groups.

Variables	Param- eters	<u>Smallest Size</u>		<u>Small Size</u>		<u>Medium Size</u>		<u>Large Size</u>	
		Coeffi- cients	Standard Errors	Coeffi- cients	Standard Errors	Coeffi- cients	Standard Errors	Coeffi- cients	Standard Errors
Intercept	α	0.044	0.420	0.036	0.511	-1.604*	0.385	-1.615*	0.838
Plot Area (in 0.01 acre)	β_1	0.356	0.258	0.493	0.306	1.388*	0.190	1.403*	0.498
	γ_1	0.011	0.010	-0.002	0.010	-0.020*	0.004	-0.004	0.012
Fertilizer (kg)	β_2	0.120	0.162	-0.052	0.238	-0.047	0.107	-0.483	0.280
	γ_2	-0.003	0.005	-0.003	0.008	0.005*	0.003	0.010	0.007
Family Labour (in man-days)	β_3	0.002	0.093	0.117	0.131	0.101	0.076	0.221*	0.100
	γ_3	0.016	0.013	0.017	0.018	-0.004	0.009	-0.023*	0.012
Hired Labour (in man-days)	β_4	0.116	0.107	0.233*	0.140	-0.109	0.110	0.300	0.203
	γ_4	0.005	0.010	0.004	0.009	0.014*	0.006	-0.011*	0.010
Number of Observations			147		86		133		68
R^2			0.58		0.66		0.72		0.79
\bar{R}^2			0.56		0.62		0.71		0.76
F-Statistics			23.77		18.66		40.63		27.37
Degrees of Freedom			(8,138)		(8,77)		(8,124)		(8,59)

* Significant at 1% level.

Significant at 5% level.

+ Significant at 10% level.

The results of the pooled data are presented in Table 4, and reveal that most of the coefficients are significant. However, tests applied above indicate that these estimates are biased because the pooled samples belong to different populations. For individual groups the signs of the coefficients are not always as expected in theory and the coefficients are not always significant. However, the signs of the β and γ coefficients for the plot area variable are, in the main, consistent with theoretical expectations (i.e. $\beta > 0$ and $\gamma < 0$) except for middle-distance, tenant operated and small farm-size groups. But for the fertiliser and the labour variables the signs of both the β and γ coefficients are not consistent.

For fertiliser, the signs of β and γ are consistent only for middle and far-distance and for small farm-size groups. Similarly, for family labour, the signs are consistent only for close-distance, owner operated and medium and large farm-size groups. In the case of hired labour input, the signs are consistent only for close and middle-distance, tenant operated and for large farm-size groups.

Comparative analysis of mean input use and yield reveals that per hectare fertiliser use is much the same for all sample groups. However, there are remarkable differences in the use of labour (both family and hired labour) and yield (Table 6). In the case of distance, yield is the highest (120 maunds per hectare) for close distance plots which could be interpreted as that close distance plots are favoured by the reliable supply of water. The pattern of input use (i.e. fertiliser and labour) is similar between close and medium distance groups. However, in general, more hired labour is used in all sample groups except in the smallest farm-size and far-distance groups. It is revealed in the table that there appears to be a definite relationship between farm-size and the type of labour used. The higher the farm-size, the less family labour is used. The opposite relationship exists with hired labour.

The results of the mean marginal products and point elasticities of the factors of production are presented in Table 7. The mean marginal product and output elasticities of plot area are much the same for all sample groups except for large farm-size groups. For the large farm-size group the marginal product of plot area is the highest and output elasticity is greater than one. At the mean of fertiliser input level marginal products are negative for far-distance plots and for small and large farm-size groups. For far-distance plots mean marginal product of fertilizer is negative. The mean fertiliser applied is 27.3 Kg., is much higher than the output maximising level of 1.57 Kg. (Table 8). On the other hand, for small and large farm-size groups the mean marginal products of fertilizer are negative because, fertiliser is applied at the stage of decreasing returns. Comparisons of labour productivities indicate that, in general, hired labourers are more productive than family labour, except for owner operated plots.

Comparisons between Tables 7 and 8, in terms of mean input use levels and output maximising levels of input reveal that in most cases, where it is possible to determine, the output maximising level of input is much higher than the mean level of input use. It appears from this result that there remains scope for increasing output by substantial increases in the levels of input use. However, as output maximising levels of all inputs in all groups could not be determined it is not possible to distinguish the differences in the technical efficiency of resources use among all the sample groups.

Conclusions and Policy Implications

It is necessary to point out that, given the nature of the functional form, determination of the output maximising levels of inputs depends on the signs of the β and γ coefficients. As mentioned earlier the regression models estimated for different sample groups did not produce theoretically ideal signs and moduli of the β and γ coefficients for all inputs used in the model. Therefore, determination of the output maximising level of some levels of input use was not possible, particularly when output response from an input was in the increasing returns stage and signs of both the β and γ coefficients of the inputs were the same. Further, when the signs are the same, the level of input which maximises output becomes negative, which is meaningless for economic interpretation. Therefore, figures from Table 8 should be interpreted carefully.

Table: 6

Mean Paddy Yield and Input Use per Hectare Under Different Sample Groups.

Groups	Yield (in maunds)	Fertiliser (in kg.)	Labour (in man-days)	
			Family	Hired
Pooled Data	114.944	244.546	91.109	127.974
<u>Plot Distance from Pump:</u>				
Close	120.160	241.997	89.216	128.686
Middle	109.183	254.273	84.742	137.716
Fur	111.013	226.609	116.911	97.124
<u>Plot Ownership:</u>				
Owner	115.954	240.454	91.741	129.490
Tenant	103.786	289.814	84.119	111.212
<u>Farm-size:</u>				
Smallest	106.586	254.671	114.047	102.671
Small	121.299	259.313	99.096	136.002
Medium	116.581	225.941	81.980	137.213
Large	122.020	240.530	48.676	155.291

Table: 7 Mean Marginal Products (MPs), Point Elasticities (PEs) and Mean Values (MVs) of Factors of Production Under Different Sample Groups.

Sample Groups	MPs	PEs	MVs	MPs	PEs	MVs
	<u>Plot Area (0.01 acre)</u>			<u>Fertilisers (kg.)</u>		
Pooled Data	0.293	0.634	32.019	0.032	0.068	31.252
<u>Plot Distance from Pump:</u>						
Close	0.357	0.733	33.151	0.041	0.083	32.393
Middle	0.268	0.611	31.155	0.047	0.107	31.047
Far	0.330	0.769	30.041	-0.085	-0.180	27.338
<u>Plot Ownership:</u>						
Owner	0.310	0.665	31.885	0.034	0.069	30.401
Tenant	0.314	0.731	33.500	0.072	0.204	40.667
<u>Farm-size:</u>						
Smallest	0.269	0.637	25.515	0.016	0.040	26.798
Small	0.204	0.431	30.956	-0.290	-0.613	31.053
Medium	0.324	0.695	34.629	0.056	0.109	31.140
Large	0.614	1.233	42.500	-0.035	-0.068	41.522
	<u>Family Labour (days)</u>			<u>Hired Labour (days)</u>		
Pooled Data	0.160	0.101	9.347	0.175	0.202	17.090
<u>Plot Distance from Pump:</u>						
Close	-0.067	-0.040	9.627	0.144	0.161	18.000
Middle	0.161	0.098	8.329	0.155	0.200	17.676
Far	0.155	0.134	11.176	0.141	0.129	11.811
<u>Plot Ownership:</u>						
Owner	0.155	0.967	9.292	0.161	0.188	17.298
Tenant	0.086	0.059	9.958	0.098	0.101	14.792
<u>Farm-size:</u>						
Smallest	0.175	0.161	9.929	0.171	0.170	10.692
Small	0.278	0.185	9.761	0.246	0.302	18.027
Medium	0.108	0.063	9.455	0.132	0.153	18.708
Large	0.151	0.052	7.333	0.004	0.005	26.789

Table: 8 Output Maximising Levels of Inputs Under Different Sample Groups.

Groups	Plot Area	Fertiliser	Family Labour	Hired Labour
Pooled Data	122.57	8.67*	NE	NE
<u>Plot Distance from Pump</u>				
Close	399.50	4.67*	4.63	179.00
Middle	NE	52.40	NE	67.75
Far	66.67	1.57	NE	8.66*
<u>Plot Ownership:</u>				
Owner	98.40	7.33*	106.00	NE
Tenant	8.31*	NE	5.38*	21.53
<u>Farm-size:</u>				
Smallest	NE	40.00	NE	NE
Small	246.50	NE	NE	NE
Medium	69.40	9.40*	25.25	7.79*
Large	350.75	48.30*	9.61	27.27

* The figure is not an output-maximising level of input and is rather to be interpreted as an output-minimising level of input i.e. beyond this level of input-use output will increase at an increasing rate.

NE Not estimated because they produce negative values for the maximum values of inputs which do not have any economic meaning.

The empirical findings of this study show that despite favourable access to inputs with an improved water management system, farm households did not benefit equally. In their study, Shand and Kalirajan (1986) also found similar results for an irrigation development project. The analysis revealed that production technologies are significantly different between sample groups. In other words, the new improved management technology was neither distance neutral nor size neutral nor tenure neutral.

The major finding of this study is that technical efficiency in production decreases with increases in the distance of irrigated plots from the source of water supply. The implication of this finding is that, within the command area of the project, access to water, declines with increasing distance of plots from the water source. It would appear that technological externalities have not been removed by the improved management technology, introduced in the IDA DTW project.

Differences in production performance among the various size and tenure groups operating within the IDA DTW project indicate different yield responses from the same level of input applications per unit of land. It could be that these differences indicate the differences between groups in the level of knowledge, or the capacity to manage irrigation and the other components of the new technology.

Another explanation of the differences in production performance could be that they arise from variations in the levels of managerial or skill efficiency of individual operators with which the improved management technology was applied. The problem could be informational as well as motivational. However, explanation of the differences due to these factors is beyond the scope of this study.

The study suffers from several limitations. Firstly, the study is limited to one-shot cross-sectional data covering only one irrigation season. Any changes resulting from such institutional development require sufficient time for the adjustment process to be completed (Schultz, 1978). Although the study was conducted during the mature stage of the project adoption of all new farming and management practices may have not been completed in all the DTW schemes, particularly in those DTWs which were installed during the completion phase of the project. Hence, the differences in the production technology may not be sustained over time with increasing knowledge of farmers and consequently their more effective application of the new technology. Secondly, inclusion of other explanatory variables such as topography and soil type in the model may have produced different results. In that respect the data were also limited.

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Appendix Tables 1-9.

Table: A-1 OLS Estimates of Transcendental Production Function Models with Distance Dummies.

Variables	Param- eters	Covariance Model		Close & Middle		Middle & Far		Close & Far	
		Coeffi- cients	Standard Errors	Coeffi- cients	Standard Errors	Coeffi- cients	Standard Error	Coeffi- cients	Standard Error
Distance Dummy-1	α_1	-0.681*	0.213	-0.529*	0.218	..	..	-0.890*	0.248
Distance Dummy-2	α_2	-0.828*	0.214	-0.684*	0.219	-0.901*	0.385	..	..
Distance Dummy-3	α_3	-0.808*	0.219	..	..	-0.874*	0.388	-1.008*	0.252
Plot Area (in 0.01 acre)	β_1	0.820*	0.117	0.614*	0.123	0.804*	0.184	1.053*	0.142
	γ_1	-0.006*	0.003	0.002	0.004	-0.008	0.005	-0.011*	0.004
Fertilizer (kg)	β_2	0.021	0.077	0.072	0.078	0.135	0.150	-0.075	0.088
	γ_2	0.002	0.002	0.001	0.002	-0.003	0.005	0.004*	0.002
Family labour (in man-days)	β_3	0.081*	0.048	0.106*	0.048	0.045	0.070	0.087	0.063
	γ_3	0.002	0.006	-0.003	0.006	0.010	0.009	-0.0001	0.008
Hired Labour (in man-days)	β_4	0.112*	0.055	0.228*	0.058	0.050	0.089	-0.011	0.004
	γ_4	0.007	0.004	-0.003	0.004	-0.012*	0.006	0.009*	0.004
Number of Observations			434		383		213		272
R^2			0.98		0.98		0.97		0.98
\bar{R}^2			0.98		0.98		0.97		0.98
F-Statistics			1770.28		1927.12		69.76		1405.54
Degrees of Freedom			(11,423)		(10,373)		(10,261)		(10,262)

* Significant at 1% level.

Significant at 5% level.

+ Significant at 10% level.

Table:A-2 OLS Estimates of Transcendental Production Function Models for Samples from different Distances from the Water Source.

Variables	Param- eters	<u>Close Distance</u>		<u>Middle Distance</u>		<u>Far Distance</u>	
		Coeffi- cients	Standard Errors	Coeffi- cients	Standard Errors	Coeffi- cients	Standard Error
Intercept	α	-0.072*	0.252	-0.577	0.446	-1.333*	0.829
Plot Area (in 0.01 acre)	β_1	0.799*	0.150	0.362*	0.224	1.400*	0.411
	γ_1	-0.002	0.004	0.008	0.008	-0.021*	0.008
Fertilizer (kg)	β_2	-0.014	0.087	0.262	0.169	0.011	0.337
	γ_2	0.003	0.002	-0.005	0.006	-0.007	0.011
Family labour (in man-days)	β_3	0.037*	0.064	0.073	0.075	0.078	0.086
	γ_3	-0.008	0.008	0.003	0.010	0.005	0.023
Hired Labour (in man-days)	β_4	0.179*	0.070	0.271*	0.103	-0.355	0.224
	γ_4	-0.001	0.004	-0.004	0.007	0.041*	0.020
Number of Observations		221		162		51	
R^2		0.77		0.64		0.56	
\bar{R}^2		0.77		0.62		0.48	
F-Statistics		92.72		33.29		6.72	
Degrees of Freedom		(8,212)		(8,153)		(8,42)	

* Significant at 1% level.

Significant at 5% level.

+ Significant at 10% level.

Table:A-3 OLS Estimates of Pooled Transcendental Production Function Models with Common Intercept for Samples from Different Distances from the Water Source.

Variables	Param- eters	<u>Close & Middle</u>		<u>Middle & Far</u>		<u>Close & Far</u>	
		Coeffi- cients	Standard Error	Coeffi- cients	Standard Errors	Coeffi- cients	Standard Errors
Intercept	α	-0.581*	0.222	-0.894*	0.384	-0.915*	0.250
Plot Area (in 0.01 acre)	β_1	0.656*	0.125	0.803*	0.184	1.073*	0.143
	γ_1	-0.001	0.004	-0.008	0.005	-0.012*	0.004
Fertilizer (kg)	β_2	-0.022	0.078	0.135	0.150	-0.094	0.088
	γ_2	0.002	0.002	-0.003	0.005	0.004 ⁺	0.002
Family labour (in man-days)	β_3	0.126*	0.049	0.045	0.070	0.095	0.063
	γ_3	-0.004	0.006	0.010	0.009	-0.001	0.008
Hired Labour (in man-days)	β_4	0.211*	0.059	0.050	0.089	0.021	0.065
	γ_4	-0.002	0.004	0.012*	0.006	0.010*	0.004
Number of Observations			383		213		272
R^2			0.71		0.58		0.72
\bar{R}^2			0.70		0.56		0.71
F-Statistics			114.30		35.53		83.16
Degrees of Freedom			(8,374)		(8,204)		(8,263)

* Significant at 1% level.

Significant at 5% level.

+ Significant at 10% level.

Table:A-4 OLS Estimates of Transcendental Production Function Models for Sample under Different Tenure Status.

Variables	Param- eters	<u>All Sample Groups</u>		<u>Owner Operated</u>		<u>Tenant Operated</u>	
		Coeffi- cients	Standard Errors	Coeffi- cients	Standard Errors	Coeffi- cients	Standard Error
Intercept	α	..	..	-0.928*	0.212	1.081	1.178
Tenancy Dummy-1	α_1	-0.718*	0.213	..	..	..	..
Tenancy Dummy-2	α_2	-0.955*	0.222	..	..	..	..
Plot Area (in 0.01 acre)	β_1	0.876*	0.117	0.984*	0.117	-0.241	0.699
	γ_1	-0.007*	0.003	-0.010*	0.003	0.029	0.024
Fertilizer (kg)	β_2	-0.041	0.077	-0.022	0.077	0.123	0.434
	γ_2	0.004*	0.002	0.003	0.002	0.002	0.009
Family Labour (in man days)	β_3	0.104*	0.047	0.106*	0.047	-0.070	0.278
	γ_3	-0.0007	0.006	-0.001	0.006	0.013	0.049
Hired Labour (in man-days)	β_4	0.091*	0.055	0.032	0.057	0.323	0.236
	γ_4	0.006*	0.004	0.009*	0.003	-0.015	0.023
Number of Observations			434		397		37
χ^2			0.98		0.70		0.62
\bar{R}^2			0.98		0.70		0.51
F-Statistics			1942.57		115.73		5.73
Degrees of Freedom			(10,424)		(8,388)		(8,28)

* Significant at 1% level.

Significant at 5% level.

+ Significant at 10% level.

Table: A-5 OLS Estimates of Transcendental Production Function Models with Farm-size Dummies.

Variables	Parameters	All Sample Groups		Smallest & Small		Small & Medium		Medium & Large	
		Coefficients	Standard Errors	Coefficients	Standard Errors	Coefficients	Standard Errors	Coefficients	Standard Errors
Farm-size Dummy-1	α_1	-0.734*	0.215	-0.165	0.299	..	..	..	..
Farm-size Dummy-2	α_2	-0.601*	0.219	-0.038	0.304	-0.094	0.059	..	..
Farm-size Dummy-3	α_3	-0.608*	0.218	..	..	-0.099*	0.053	-1.692*	0.333
Farm-size Dummy-4	α_4	-0.553*	0.227	..	..	..	..	-1.668	0.345
Plot Area (in 0.01 acre)	β_1	0.826*	0.118	0.471*	0.181	0.687*	0.099	1.426*	0.171
	γ_1	-0.006*	0.003	0.003	0.006	-0.004	0.003	-0.017*	0.004
Fertilizer (kg)	β_2	-0.009	0.077	0.076	0.127	-0.067	0.090	-0.114	0.096
	γ_2	0.003	0.002	-0.001	0.004	0.005*	0.002	0.006*	0.002
Family Labour (in man-days)	β_3	0.098*	0.048	0.035	0.073	0.124*	0.056	0.144*	0.060
	γ_3	0.0005	0.006	0.014	0.010	-0.003	0.007	-0.010	0.007
Hired Labour (in man-days)	β_4	0.082	0.055	0.164*	0.075	0.073	0.075	-0.059	0.090
	γ_4	0.006*	0.004	0.004	0.004	0.006	0.004	0.009*	0.005
Number of Observations			434		233		287		201
R^2			0.98		0.97		0.98		0.99
\bar{R}^2			0.98		0.97		0.98		0.99
F-Statistics			1610.66		795.19		1575.66		1329.15
Degrees of Freedom			(12,422)		(10,223)		(10,277)		(10,191)

* Significant at 1% level.

Significant at 5% level.

+ Significant at 10% level.

Table: A-6 OLS Estimates of Transcendental Production Function Models for Different Farm-size Groups.

Variables	Param- eters	<u>Smallest Size</u>		<u>Small Size</u>		<u>Medium Size</u>		<u>Large Size</u>	
		Coeff- cients	Standard Errors	Coeff- cients	Standard Errors	Coeff- cients	Standard Errors	Coeff- cients	Standard Errors
Intercept	α	0.044	0.420	0.036	0.511	-1.604*	0.385	-1.615*	0.838
Plot Area (in 0.01 acre)	β_1	0.356	0.258	0.493	0.306	1.388*	0.190	1.403*	0.498
	γ_1	0.011	0.010	-0.002	0.010	-0.020*	0.004	-0.004	0.012
Fertilizer (kg)	β_2	0.120	0.162	-0.052	0.238	-0.047	0.107	-0.483	0.280
	γ_2	-0.003	0.005	-0.003	0.008	0.005*	0.003	0.010	0.007
Family Labour (in man-days)	β_3	0.002	0.093	0.117	0.131	0.101	0.076	0.221*	0.100
	γ_3	0.016	0.013	0.007	0.018	-0.004	0.009	-0.023*	0.012
Hired Labour (in man-days)	β_4	0.116	0.107	0.230*	0.140	-0.109	0.110	0.300	0.203
	γ_4	0.005	0.010	0.004	0.009	0.014*	0.006	-0.011*	0.010
Number of Observations			147		86		133		68
R^2			0.58		0.66		0.72		0.79
\bar{R}^2			0.56		0.62		0.71		0.76
F-Statistics			23.77		18.66		40.63		27.37
Degrees of Freedom			(8,138)		(8,77)		(8,124)		(8,59)

* Significant at 1% level.

Significant at 5% level.

+ Significant at 10% level.

Table: A-7 OLS Estimates of Pooled Transcendental Production Function Models with Common Intercepts for Different Farm-size Groups.

Variables	Parameters	All Sample Groups		Smallest & Small		Small & Medium		Medium & Large	
		Coefficients	Standard Errors	Coefficients	Standard Errors	Coefficients	Standard Errors	Coefficients	Standard Errors
Intercept	α	-0.736*	0.216	-0.160	0.301	-1.091*	0.269	-1.715*	0.328
Plot Area (in 0.01 acre)	β_1	0.858*	0.118	0.473*	0.183	1.074*	0.141	1.435*	0.170
	γ_1	-0.007*	0.003	0.002	0.006	-0.012*	0.004	-0.017*	0.004
Fertilizer (kg)	β_2	-0.026	0.077	0.086	0.128	-0.057	0.087	-0.112	0.095
	γ_2	0.003	0.002	-0.002	0.004	0.005*	0.002	0.006*	0.002
Family Labour (in man-days)	β_3	0.098*	0.048	0.036	0.074	0.144*	0.055	0.144*	0.060
	γ_3	0.0003	0.006	0.015	0.010	-0.006	0.007	-0.010	0.007
Hired Labour (in man-days)	β_4	0.099*	0.056	0.160*	0.076	0.041	0.074	-0.058	0.090
	γ_4	0.006*	0.004	0.006	0.006	0.007*	0.004	0.009*	0.005
Number of Observations			434		233		287		201
R^2			0.68		0.62		0.71		0.74
\bar{R}^2			0.67		0.60		0.70		0.73
F-Statistics			110.92		44.75		84.43		69.95
Degrees of Freedom			(8,425)		(8,224)		(8,278)		(8,192)

* Significant at 1% level.

Significant at 5% level.

+ Significant at 10% level.

Table: A-8 Descriptions of the Estimated OLS Models for Different Sample Groups.

Equation Number.	Description of Estimated Models	Sum of Squared Residuals (SSR)	No. of Obs. (N)	No. of Parameters (K)
1.	Covariance Model with Distance Dummies	$SSR_1 = 61.346$	434	$K = 11$
2.	Regression Model for Close Distance Plots	$SSR_2 = 22.792$	221	$K-1 = 8$
3.	Regression Model for Medium Distance Plots	$SSR_3 = 25.368$	162	$K-1 = 8$
4.	Regression Model for Far Distance Plots	$SSR_4 = 8.913$	162	$K-1 = 8$
5.	Covariance Model with Close and Medium Distance Dummies	$SSR_5 = 48.752$	383	$K = 10$
6.	Pooled Model with Common Intercept for Close and Medium Distance Plots	$SSR_6 = 50.887$	383	$K-1 = 8$
7.	Covariance Model with Medium and Far Distance Dummies	$SSR_7 = 37.519$	213	$K = 10$
8.	Pooled Model with Common Intercept for Medium and Far Distance Plots	$SSR_8 = 37.548$	213	$K-1 = 8$
9.	Covariance Model with Close and Far Distance Dummies	$SSR_9 = 34.570$	272	$K = 10$
10.	Pooled Model with Common intercept for Close and Far Distance Plots	$SSR_{10} = 35.121$	272	$K-1 = 8$
11.	Covariance Model with Tenancy dummy	$SSR_{11} = 61.635$	434	$K = 10$
12.	Regression Model for Owner Operated Plots	$SSR_{12} = 50.078$	397	$K-1 = 8$
13.	Regression Model for Tenant Operated Plots	$SSR_{13} = 9.552$	37	$K-1 = 8$
14.	Pooled Model with Common Intercept for All Groups	$SSR_{14} = 63.456$	434	$K-1 = 8$
15.	Covariance Model with Farm size Dummies	$SSR_{15} = 61.654$	434	$K = 12$
16.	Regression Model for Smallest Farm-size	$SSR_{16} = 25.323$	147	$K-1 = 8$
17.	Regression Model for Small Farm-size	$SSR_{17} = 11.388$	86	$K-1 = 8$
18.	Regression Model for Medium Farm size	$SSR_{18} = 15.191$	133	$K-1 = 8$
19.	Regression Model for Large Farm size	$SSR_{19} = 9.127$	68	$K-1 = 8$
20.	Covariance Model with Smallest and Small Farm-size Dummies	$SSR_{20} = 37.218$	233	$K = 10$
21.	Pooled Model with Common Intercept for Smallest and Small Farm-size	$SSR_{21} = 38.029$	233	$K-1 = 8$
22.	Covariance Model with Small and Medium Farm-size Dummies	$SSR_{22} = 36.326$	287	$K = 10$
23.	Pooled Model with Common Intercept for Small and Medium Farm-size	$SSR_{23} = 34.768$	287	$K-1 = 8$
24.	Covariance Model with Medium and Large Farm-size Dummies	$SSR_{24} = 21.549$	201	$K = 10$
25.	Pooled Model with Common Intercept for Medium and Small Farm-size	$SSR_{25} = 21.572$	201	$K-1 = 8$

Table: A-9

Test of Differentials in Production Functions.

Test Characteristics	Constrained SSRs	Unconstrained SSRs	F-Statistics	Degrees of Freedom	Critical (5%) Value
<u>Test of Differential Intercepts</u>					
<u>Plot Distance from Pump:</u>					
Close Vs. Middle	SSR ₆	SSR ₃	16.334	(1,373)	3.84
Middle Vs. Far	SSR ₈	SSR ₇	0.157	(1,103)	3.92
Close Vs. Far	SSR ₁₀	SSR ₉	4.176	(1,262)	3.92
<u>Plot Ownership:</u>					
Owner Vs. Tenant	SSR ₁₄	SSR ₁₁	12.527	(1,424)	3.84
<u>Farm-size:</u>					
Smallest Vs. Small	SSR ₂₁	SSR ₂₀	4.859	(1,223)	3.84
Small vs. Medium	SSR ₂₃	SSR ₂₂	-11.880	(1,227)	3.84
Medium Vs. Large	SSR ₂₅	SSR ₂₄	0.204	(1,191)	3.84
<u>Test of Differential Slopes Vectors</u>					
<u>Plot Distance from Pump:</u>					
Close Vs. Middle	SSR ₃	SSR ₂ + SSR ₃	0.561	(8,365)	1.94
Middle Vs. Far	SSR ₇	SSR ₃ + SSR ₄	2.302	(8,95)	2.02
Close Vs. Far	SSR ₉	SSR ₂ + SSR ₄	2.869	(8,256)	1.94
<u>Plot Ownership:</u>					
Owner Vs. Tenant	SSR ₁₁	SSR ₁₂ + SSR ₁₃	1.748	(8,416)	1.94
<u>Farm-size:</u>					
Smallest Vs. Small	SSR ₂₀	SSR ₁₆ + SSR ₁₇	0.371	(8,215)	1.94
Small vs. Medium	SSR ₂₂	SSR ₁₇ + SSR ₁₈	12.331	(8,269)	1.94
Medium Vs. Large	SSR ₂₄	SSR ₁₈ + SSR ₁₉	-2.605	(8,183)	1.94
<u>Test of Differential Regression Across Groups</u>					
<u>Plot Distance from Pump:</u>					
Close Vs. Middle	SSR ₆	SSR ₂ + SSR ₃	2.296	(9,365)	1.88
Middle Vs. Far	SSR ₈	SSR ₃ + SSR ₄	2.065	(9,95)	1.96
Close Vs. Far	SSR ₁₀	SSR ₂ + SSR ₄	3.041	(9,256)	1.88
<u>Plot Ownership:</u>					
Owner Vs. Tenant	SSR ₁₄	SSR ₁₂ + SSR ₁₃	2.966	(9,424)	1.88
<u>Farm-size:</u>					
Smallest Vs. Small	SSR ₂₁	SSR ₁₆ + SSR ₁₇	0.858	(9,215)	1.88
Small vs. Medium	SSR ₂₃	SSR ₁₇ + SSR ₁₈	9.209	(9,269)	1.88
Medium Vs. Large	SSR ₂₅	SSR ₁₈ + SSR ₁₉	-20.333	(9,183)	1.88