The relative efficiency of water use in Bangladesh agriculture

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Abstract

This study examines whether water use is efficient in Bangladesh agriculture compared to other inputs. As agriculture is the major water using sector and water is most scarce during winter due to low annual rainfall, the government here runs many irrigation projects. Recently Bangladesh Water Development Board (BWDB) leased out these projects to various water user groups for maintenance and expenditure recovery. This study estimates a translog production function for *boro* rice in the 7 hydrological regions and derives marginal products of various inputs. Production functions are estimated using data collected by International Rice Research Institute (IRRI) on expenditures of agricultural inputs and returns on investment from a nationally representative sample of 1928 farm households from 64 districts of Bangladesh. Results show that irrigation water use is less efficient compared to other agricultural inputs, like land, labour, fertiliser and ploughing with power tiller.

Keywords: relative efficiency, marginal product, production function, irrigation water, *boro* rice, Bangladesh agriculture
JEL: Q13, Q25

1. Introduction

Water is scarce and agriculture is the major water-using sector in Bangladesh. Water is most scarce in the southwest and northwest regions during the dry season due to low annual rainfall. Being a country of 140 million inhabitants, agriculture is still the major water using sector in order to feed a growing population where at least 40 million people do not have a square meal. Demand for both surface and groundwater for irrigation is on the rise in the dry winter season which is 58.6 percent of total demand for water. The principal crop during this season is *boro* rice, occupying about 70 percent of crop production uses up a lot of water in the production process compared to wheat or potato. According to one estimate of BISWAS and MANDAL (1993), the quantity is 11, 500 m^3 per hectare (ha). This paper seeks to examine whether water use is efficient in Bangladesh agriculture relative to other inputs.

There are many government run canal irrigation projects in the country. Between 1944 and 1999 Bangladesh Water Development Board (BWDB) spent more than US$1,700 m on flood control drainage irrigation (FCDI) projects. Recently BWDB leased out the irrigation projects to the Water User Groups (WUG) (mainly medium and large farmers) for maintenance and cost recovery on the basis of average pricing. This gives rise to a potential conflict of interests between very small/small farmers and WUG and hence it is not functional as it should be.

Moreover, water has many other uses in society, namely fisheries, navigation, mangrove forests, river morphology, and not to mention household and industrial uses. Therefore, during the dry season water has a high opportunity cost or scarcity value due to competition from all the uses in addition to upstream intervention. It is imperative that farmers pay the true opportunity costs of irrigation water from the perspective of sustainable water use. Currently the public sector is responsible for maintaining the surface water irrigation projects which is only 10 percent of the total irrigation. The rest is the private sector mainly groundwater irrigation using minor irrigation devices. Against this backdrop the present study first attempts to examine whether dry season water use is efficient in Bangladesh agriculture vis-à-vis other inputs.

The overall study goal is to see whether farmers allocate irrigation water efficiently in agricultural production in Bangladesh. The specific research objectives are to estimate the marginal value product of water and compare it with the marginal returns of other inputs in *boro* rice production. Whether returns to factor inputs are equal will be tested using Bangladeshi data for *boro* rice. As food security and employment generation are still major development challenges for Bangladesh, this study would have important policy implications for irrigation water use and crop production in agriculture. The marginal value estimates will give a rational basis of water allocation on the basis of efficiency. For instance the lack of marginal pricing can be identified as one major factor responsible for present policy failure of the BWDB. The analysis in this paper is novel in the context of Bangladesh agriculture since to my knowledge only one such study has been done so far, which is in the context of Vietnam (LINDE-RAHR, 2005).

The paper explores the possibility that the technology used in *boro* rice production can be adequately explained by the translog specification. The translog production function is a flexible specification, exhibiting non-homothetic technology and imposes no restrictions on the magnitude of elasticity of substitution between inputs or on the returns to scale. Due to its flexibility, this specification has been widely used in the study of input substitution, productive efficiency, technical change and productivity growth. The function is also used to estimate cost sharing equations by imposing the condition of constant returns to scale and assuming perfectly competitive input and output markets.

In this study *boro* rice production function is estimated using cross section data collected by International Rice Research Institute (IRRI) on costs of agricultural inputs and returns on investment from a nationally representative sample of 1928 farm households from 62 villages belonging to 57 of 64 districts of Bangladesh. Elasticities of output with respect to various inputs and marginal products are also estimated. The next section presents a review of various studies done on efficiency of input use and discusses how they relate to this study. Section 3 gives a brief description of the study area. Section 4 discusses the data and the variables used. In section 5 research methods, econometric specification of the function to be estimated and the hypotheses to be tested are developed. Section 6 presents and discusses the estimated results. Finally the paper is concluded in section 7 with a summary and some policy recommendations.

2. Efficiency of input use

Most studies in efficiency of input use in the literature are based on production function estimates. Production functions assume specific field application efficiency. All estimates regardless of the methods to derive them depend on assumptions about the technology or efficiency of the irrigation system. Irrigation water efficiency increases with a rise in crop price and an improvement in irrigation efficiency.

There is really a dearth of relevant empirical work in the literature when it comes to relative efficiency. The studies done in Indian agriculture measures the absolute efficiency of water use but the methodology used is quite dated (VAIDYANATHAN, 2004). SOMANATHAN and RAVINDRANATH (2006) estimated the marginal value of groundwater in Indian agriculture on the basis of actual water trades in the state of Andhra Pradesh (AP). BANERJI et al. (2006) studied the efficiency of groundwater use for sugarcane in North India estimating a Cobb-Douglas production function.

JACOBY (1992) estimated the productivity of men and women in peasant agriculture of the Peruvian Sierra using household data from the Peruvian Living Standards Survey. He estimated a Cobb-Douglas ‘pseudo’-production function where he regressed the logarithm of the value of crop output on the logarithms of all input costs in Peru. He also found the OLS estimates of a restricted translog production function. His results suggest that marginal productivities of men and women are significantly positive but male labour is more productive than female labour and that the two types of labour cannot be aggregated.

In a separate study, JACOBY (1993) estimated an agricultural production function with different types of labour (men, women and children) as distinct inputs in the Peruvian highlands. He estimated the opportunity cost of time or shadow wages. The marginal product of labour is calculated for each household. He estimated both Cobb-Douglas and translog production function and derived both OLS and instrumental variable (IV) estimates of the Cobb-Douglas production function. Since the correlation between marginal products for male and female labour was very high, the labour supply parameter estimates from the OLS and instrumental variable method did not differ much although the OLS estimates were more efficient. Further, since Cobb-Douglas production function imposes strong separability between male/female labour and other inputs, he estimated an OLS version of the translog flexible functional form to derive the shadow wages. The present study also finds an unrestricted translog function to be a better specification for *boro* rice production in Bangladesh.

UDRY (1996) showed that households do not always reach efficient factor allocation in production. He found striking evidence of important inefficiencies in factor allocation across plots controlled by different households in the same village. He found that yields are 30 percent lower on plots controlled by women than on plots controlled by men with the same crop in the same year in the same household. The marginal product of land controlled by a woman is less than that of similar land controlled by her husband. Therefore, a reallocation of land from a woman to her husband would increase total output. But a woman's opportunity cost may be lower than men. According to this study in the villages of Burkina Faso, there is much more variation in yields across similar plots controlled by different households than there is variation in yields across plots controlled by individuals in the same household[1].

In the Bangladesh context to date there has been no study testing the allocative efficiency of input use in agriculture. Previous studies are based on absolute efficiency. CHOWDHURY (2005) found high economic value of water in southwest, southeast and northwest regions of Bangladesh. In the developing country context one study was done by LINDE-RAHR (2005) who tested the relative efficiency of input use in Vietnamese agriculture. He assumes risk neutral households and examines the ability of households to allocate factor inputs efficiently within the household. His results suggest that within households efficiency does indeed hold.

LINDE-RAHR (2005) maximised a joint profit function which includes two production functions for rice and sugarcane:

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1 However, this homogeneity assumption in terms of soil quality and other characteristics of the two sets of plots may not be tenable.

$$\pi = p^j f^j \left(Y^j\right) - (\omega + q_i)\left(I^j + x^j\right),$$

where π = profit

p^j = crop price, j = rice, sugarcane

f^j = production function

Y^j = crop yield

ω = water price

q_i = other input prices, i = index for inputs

I^j = water used in crop j

x_i^j = all other inputs used in crop j

He estimated a seemingly unrelated regression (SUR) model by assuming that inputs are substitutable between these crops. If risk profiles across activities differ, he anticipates that inefficiencies and differences in factor returns will exist. Market failures due to asymmetric information can also lead to inefficient resource allocation. The major methodological difference from LINDE-RAHR'S 2005 study is that I estimate a single production function for *boro* rice and the marginal productivity of water relative to other inputs for 7 hydrological regions of Bangladesh and assess whether the marginal value product varies significantly among them. I estimate a translog production function where the dependent variable is the value of *boro* rice output.

It must be noted that LINDE-RAHR'S study is based on a sample size of 170 households from only one district in Vietnam. Therefore in terms of sample size and area coverage, the present study is more comprehensive since it uses a nationally representative sample of 724 agricultural households randomly drawn from all of Bangladesh.

3. Study area

Bangladesh may be divided into 7 hydrological regions. Agriculture is the major water-using sector for surface and groundwater irrigation with rice cultivation, the single most important activity in the economy. The crop calendar is based on the temporal distribution of rainfall and temperature throughout the year. Three primary cropping seasons are pre-monsoon, monsoon and winter or dry season. *Aus* is the pre-monsoon variety while *Aman* is rain fed monsoon (wet season) rice and *boro* is (irrigated) dry season rice. *Aman* is the leading rice crop occupying about 51 percent of the total rice cultivated area followed by *boro* (40 percent) and *aus* (9 percent) (BANGLADESH BUREAU OF STATISTICS, 2008). A remarkable feature of the rice growth pattern is the rising share of irrigated HYV (high yielding variety) *boro* rice. Other major crops are wheat, jute, sugarcane, oilseeds, pulses, potato, onion, spices and vegetables.

Precipitation pattern is dominated by rainfall characteristics. The average annual rainfall varies from 1,200 mm in the extreme west to over 5,000 mm in the northeast (WORLD BANK, 2000). Four seasons can be identified on the basis of rainfall patterns. About 80 percent of the total rainfall occurs during the monsoon from June to September. Combining the post-monsoon (October-November) and winter periods (December-February) only 10 percent of the annual rainfall is available (WORLD BANK, 2000). Rainfall is extremely unreliable in the subsequent pre-monsoon period (March-May) as well. On an average there is about 10 percent of the annual rainfall in this period (WORLD BANK, 2000). On the whole there is a seasonal lack of water depending on the presence and the duration of the monsoon. Water is very scarce in the south and northwest regions of Bangladesh during the winter (December-February).

The southwest region is the Ganges dependent region which suffers from dry season water scarcity due to the Farakka Barrage. It also suffers from arsenic contamination. In the coastal zone most shallow groundwater is saline and surface water salinity is also widespread. In the inland area shallow tube well (STW) irrigation has evolved intensively. The southeast region has an inland zone and a coastal zone. There is a widespread STW irrigation in the inland area. The coastal zone suffers from drainage congestion, salinity intrusion and high cyclone risks. It is also the region worst affected by arsenic contamination of groundwater.

The northwest region is highly developed agriculturally with the largest irrigated area of all regions supplied mainly by shallow tube wells. Due to STW pumping irrigation, seasonal water table decline is widespread. The southern part of this region is very flood prone. Some of the country's biggest flood control drainage and irrigation schemes are located in this area. The North central region is the most industrialized and urbanized region in the country and it includes the capital city (Dhaka). This region suffers from seasonal water table decline problem due to intensive STW irrigation.

In the Eastern Hills, land is mainly irrigated by low lift pumps (LLP) since shallow tube well irrigation is limited due to groundwater salinity. The scope for substantially increasing irrigation water availability is limited by the dry season flow. The south central region does not have the same dry season water shortage problem as the southwest region. However, it is much more vulnerable to cyclones and storm surges in the coastal zone and has a serious arsenic problem. Irrigation is mainly confined to the less saline area. Both LLP and STW are being used for irrigation. Due to aquifer arsenic problems, the northeast region has relatively little exploitable shallow groundwater but has more abundant dry season surface water resources. Most irrigation is therefore done by low lift pumps rather than shallow tube wells.

4. Data and variables

International Rice Research Institute (IRRI) conducted an Agricultural Household Survey in Bangladesh in 2000 for 3 crop seasons and collected data on expenditures of inputs (including irrigation water) and returns on investment from a nationally representative sample of 1,880 farm households from 62 villages belonging to 57 of 64 districts of Bangladesh. Initially 64 unions[2] (one union to represent each of the 64 districts) were selected from the list of all unions using a random number table (HOSSAIN et al., 2007). In the second stage two villages were chosen from each union which were similar both in terms of population size and literacy rates of the unions. When the 'first-choice' village was uncooperative, the second choice was included in the sample. Two unions were discarded later due to problems in administering the survey. The census of the selected villages enumerated 9,874 households or 159 households per village. These households in the villages were classified into 4 groups, rich, solvent, poor and very poor using the wealth-ranking method of the participatory rural appraisal (PRA) technique. A sample of 30 households was drawn from each of these 4 groups proportional to their weights using stratified random sampling method.

In this study I use an updated and more recent version (2004) of the same dataset from IRRI. The 2004 survey collected expenditure and returns data only for the largest plot of the land portfolio of farmers. Hence the sample size is larger because some households have been transformed into several due to separation within the extended family (HOSSAIN, 2006). A few households migrated out and they were replaced with new entries from the same "wealth ranking group". The sample in this survey consists of 1928 households. There are 1,104 rice farmers. But my estimations include only those households that produce *boro* rice during the dry season. They are 724 in number from 7 hydrological regions. In the context of developing countries this dataset collected by IRRI is very rich particularly in terms of information on returns of different types of agricultural labour and other inputs.

The dependent variable is the value of rice output in BDT (Bangladesh Taka[3]). Ploughing expenditure measured in BDT consists of expenditure on power tiller and wage bill for hired draught power. Labour days consist of both family and hired labour. Labour is used for mainly ploughing, sowing, weeding, harvesting and threshing. Irrigation is the total irrigation expenditure measured in BDT and we do not know the price per unit of water or the number of hours used for pumping water. The expenditure on irrigation is basically the cost of pumping water which includes energy

[2] A union is the smallest administrative unit composed of several villages. Districts are divided into upazilas and upazilas are further divided into unions.

[3] 1 USD = 58 BDT in 2004

expenditure (electricity or diesel) and hiring pump mechanics. The energy (diesel) prices are fairly uniform throughout the country, though at times of shortage and power outage; these can vary depending on local availability. Farmers use low lift pumps for pumping water from surface water sources and shallow and deep tube wells from aquifers and groundwater. Seeds and fertilisers are measured in kilogramme (kg). Farmers mainly use urea and TSP besides phosphate and other chemical fertilisers. Only expenditure data measured in BDT are available for pesticides and manure use. Land is measured in ha and includes both own and sharecropped land that is devoted to *boro* rice cultivation. This is essentially a sample of very small farmers, which is highly appropriate since the average farm size in Bangladesh is 0.68 ha. The average plot size is 0.16 ha in the present sample.

There are 5 types of soil in Bangladesh. Loamy is a good quality soil containing sand, clay and organic matter. Sandy loam has sand as a larger portion of the soil contents than other particles. Clay is heavy soil. Clay loam has clay as a larger portion of the soil contents than other particles. Sand is light soil. I have categorized them into 3 categories according to clay contents, light, heavy and medium. Loamy is medium, sandy loam is light and clay loam is heavy soil.

In Bangladesh low land is defined as land which is under chest deep water during the months of August and September. Land type 3 and 4 are normally known as lowland and very lowland, respectively. Very lowland remains under water for more than 9 months in a year. Land type 2 is categorized as medium land normally flooded up to about 90 cm (knee) deep during the flood season. High land is where there is very little standing water during this period. Land type 1 is not flooded and is considered to be highland.

5. Methods

The research question I address is whether dry season irrigation water use is efficient in Bangladesh. If the households are efficient, each household will equate the value of marginal physical product of water with its price as well as the marginal rate of technical substitution between water and any other input. I, therefore, test a hypothesis whether the return from water and the marginal rate of technical substitution (MRTS) of water and any other input in rice production are equal among Bangladeshi households. If in a village marginal value product of any one farmer is not equal to that of other farmers then there is inefficiency of water use. A basic element for measuring the efficiency of input use in agriculture is a production function that relates crop production to the use of various inputs. The marginal physical productivity of inputs for each incremental application is estimated and the marginal value of each increment is the marginal physical product times the crop price.

A number of different flexible functional forms can be estimated including the translog form. In this study I first estimate the OLS form of the Cobb-Douglas production function where both the dependent and the input variables are in log form. After estimating the OLS Cobb-Douglas production function, I estimate the OLS translog form and their marginal products. The translog form provides a greater variety of substitution possibilities than those restricted by constant elasticity of substitution. Therefore this form is widely used in the empirical analyses of production technology and factor markets.

The translog production function can be written as:

(1)
$$\ln Y_j = \beta_0 + \sum_{i=1}^{n} \beta_{ji} \ln x_{ji} + \frac{1}{2}\left\{\sum_{i=1}^{n}\sum_{l=1}^{n} \beta_{il} \ln x_{ji} \ln x_{jl}\right\} + \sum^{k} \delta_{jk} type_k + \sum^{h} \lambda_{jh} land_h + \sum \gamma_r (\ln IH_r) + \mu_j$$

Where $\ln Y_j =$ log of total production of crop- j

$\ln x_{ji} =$ log of input $i = 1,...,n.$ (including irrigation expenditure, I)

$type_k$ = irrigation type dummies (k = LLP, STW etc.)

$land_h$ = land type dummies (h: elevation and soil quality)

$\ln IH_r$ = log of irrigation expenditure*regional dummies

H_r = regional dummies; $r = 1,...,7.$

I assume symmetry of cross product terms that is $\beta_{il} = \beta_{li}$ (GREENE, 2000). μ_j is a random error assumed to be $iid[0, \sigma_u^2]$.

The elasticity of output with respect to each factor of production is calculated by taking the partial derivative of output with respect to the factor under consideration. For irrigation water (I), the elasticity can be derived as:

(2)
$$\varepsilon_j = \frac{\partial \ln Y_j}{\partial \ln I} = \beta_i + 2\beta_{ii} \ln x_i + \sum_{l \neq i} \beta_{il} \ln x_l + \gamma_r H_r$$

The marginal productivity of water in crop- j is then:

(3)
$$\rho_j = \frac{\partial Y_j}{\partial I} = \frac{\partial \ln Y_j}{\partial \ln I} * \frac{Y_j}{I} = \varepsilon \frac{Y_j}{I}$$

In a similar fashion it is possible to calculate the marginal productivity of all other factors of production.

If Y is the total value of rice output, equation (3) then gives the marginal value of water for rice. A price elasticity of water can also be derived if the water price ω is assumed to equal the marginal value of water use. For a profit maximising farmer the marginal value of water is equal to its marginal cost. One can thus define η as price elasticity of water use as follows:

(4) $$\eta = \frac{\partial \ln I}{\partial \ln \omega} = \frac{\partial \ln I}{\partial \ln \rho}.$$

A profit maximising household equates the marginal value product of inputs with its price. The marginal return on water and input x_i in terms of rice production function is

(5) $$p^{rice} \frac{\partial f^{rice}}{\partial I^{rice}} = \omega$$

$$p^{rice} \frac{\partial f^{rice}}{\partial x_i^{rice}} = q_i ,$$

where p^{rice} is rice price, f^{rice} is the production functions, I^{rice} is water used in rice; x_i^{rice} represents all other inputs and ω and q_is are water and other input prices as already cited above.

Hypotheses

In this section I discuss the expected sign on the coefficients of the explanatory variables included in the estimation of production function. All inputs, namely, land, ploughing expenditure, labour, seed, fertilizer, irrigation, manure and pesticides are each expected to have a positive effect on output. The sign of the coefficients on the irrigation type variables (STW, DTW) cannot be predicted a priori. Similarly I cannot determine the sign of the coefficients of land of different elevations and soil quality which are dummy variables as well. The sign of irrigation expenditure in different hydrological regions are also unpredictable where there are 6 regional dummies for 7 hydrological regions. Doubling all input, i.e., doubling each type of input expenditure in this model is expected to have a positive impact on output. However, I am not sure about the sign of the complementary input terms on output.

If in a village MVP of water for any one farmer is not equal to that of another farmer then there is inefficiency of water use. In order to check whether it is profitable for farmers to use water efficiently we examine whether the MVP of water at the village level is equal to one. If all the farmers in one village face about the same price of rice then it is profitable for farmers to use water efficiently. However, there is some variation in *boro* rice price at the village and regional level (the coefficient of variation is 9.5 percent in this dataset). Since the left hand side variable (*boro* rice output) is measured in value terms this variation in output price has already been captured by this.

6. Results and discussions

I use a standard F test in identifying the appropriate production function specification for *boro* rice. The preferred specification is the original translog function as specified by equation (1) above. The results from the unrestricted translog production function are discussed below. The results are corrected for heteroscedasticity.

Discussion of results

Output is higher on medium and very lowland compared to high land. The rise in irrigation expenditure in northeast, eastern hills and southeast regions exert a negative impact on output. Irrigation expenditure is lowest in the northeast region. It is highest in northwest and north central regions. Doubling the amount of irrigation and fertiliser expenses increases output significantly. The correlation between irrigation and fertiliser is 0.55. The joint increase of labour and irrigation expenditure has a negative impact on output.

An increase in ploughing expenditure of draft animals has a significant negative impact on output. However, the ploughing expenditure of power tiller has a significant positive effect on output. Both these results suggest that mechanization of agriculture will increase *boro* rice output. Labour also has a significant positive impact on output. Agricultural labour is very productive during the dry *boro* season. However, the effect decelerates as indicated by the negative squared term for labour. Fertilizer is showing a negative impact on output probably due to soil degradation from long term use of chemical fertilizer in *boro* rice production.

Table 1 presents elasticity of *boro* rice output with respect to various inputs. Agricultural land has the highest elasticity (0.54). The value of *boro* rice output is very inelastic in response to a change in irrigation expenditure. The percentage increase in value of *boro* rice output is only 1 percent of the increase in irrigation expenditure.

Table 1. Elasticity estimates from translog production function

Input	Elasticity
Land	0.54
Very low land	0.54
Medium land	0.6
High land	0.59
Labour	0.21
Ploughing with power tiller	0.18
Irrigation	0.01
Fertiliser	0.13

Source: own estimations

Marginal return

From these elasticity estimates marginal returns are estimated and reported in table 2. The marginal return on one ha land is BDT 18, 319.97. Medium land has a higher marginal return than high land and very low land. The marginal return of one additional labour day is BDT 52.41. The marginal return of ploughing with power tiller is BDT 3.44. That is one BDT increase in expenditure of ploughing with power tiller increases *boro* rice output by BDT 3.44. The marginal return of irrigation water is 0.05; i.e., one BDT increase in irrigation expenditure raises output by only BDT 0.05. The marginal return on fertiliser is BDT 12.42 per kg. The significance of the marginal returns is tested; these are significant at conventional levels. In terms of relative efficiency of input use land use is more efficient than labour. Labour use in turn is more efficient than fertiliser, ploughing with power tiller and irrigation.

Table 2. Marginal returns of inputs at sample mean in BDT

Input	Marginal Return
Land	18,319.97
Very low land	19,270.61
Medium land	19,846.16
High land	18,795.94
Labour	52.41
Power tiller	3.44
Irrigation	0.05
Fertiliser	12.42

Source: own estimations

Irrigation is the least efficient compared to land, labour, fertiliser and power tiller. In general *boro* rice production requires 3 times more water than wheat or maize due to seepage and percolation in addition to evapo-transpiration for normal crop production. The Bangladesh Rice Research Institute (BRRI) scientists[4] also found that farmers use more water than required as demonstrated from the experimental plots. On the other hand there is a certain requirement of irrigation water for *boro* rice production below which there will be less or no output per ha or overuse will destroy the rice plants. The water requirement for irrigation varies with soil moisture, temperature, annual rainfall and *boro* rice variety.

Table 3 reports input and output price variations. In case of irrigation, ploughing, manure and pesticides the variation represents variation in total expenditure. Direct and physical input is not available. Expenditure is a proxy for the intensity of input use. If unit price is fairly constant, an increase in expenditure implies larger quantity of the input. Hence these results would improve with better data. For instance if we had known the price of irrigation water per unit we could have compared the marginal product with its price. There is no information in the dataset on how much water farmers are using to irrigate (neither) their rice fields nor the number of hours the irrigation pumps are used. The expenditure on irrigation consists of the volume of water used in the rice fields and the price per unit of irrigation water. Farmers in Bangladesh do not pay for using water as such; they pay for pumping water which is the expenditure of energy (fuel, diesel or electricity) and hiring pump mechanics if required. Electricity and diesel cost 40 to 75 percent of the average variable cost of irrigation expenditure per ha[5], while monthly wage of pump mechanic is 25 to 60 percent of total irrigation expenditure. There is a 40 percent variation in monthly wages of pump mechanics.

Table 3. Output and input price variation in percentage

Boro rice	9.5
Irrigation expenditure	96
Ploughing by draft animals	423
Ploughing by power tiller	93
Manure	215
Pesticides	135

Source: own estimations

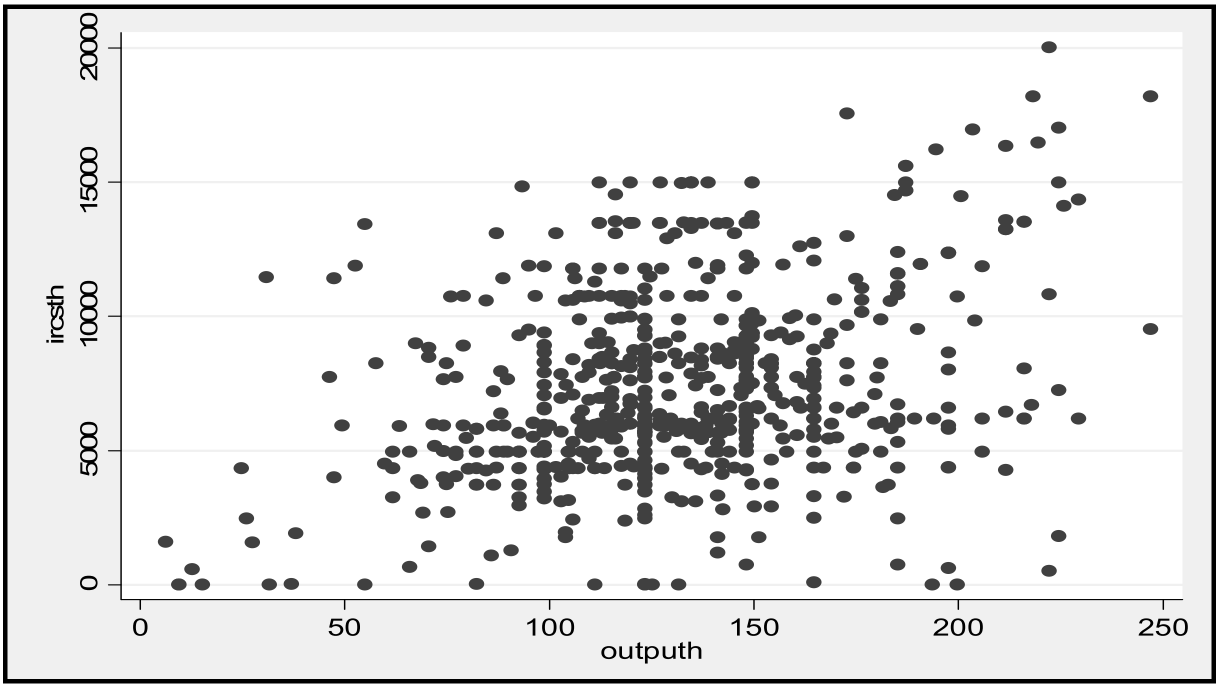
In rural Bangladesh due to lack of electricity connection in many villages and frequent power outages, farmers still depend on diesel for running their irrigation pumps to a

4 Personal communication with Dr A. Sattar, Director General (BRRI).

5 The figures are confirmed by author's field research.

great extent. Diesel is taxed whereas electricity is subsidised. However, the ratio of diesel to petrol prices in Bangladesh reflects a lower taxation of diesel among other fuel oils indicating a preferential treatment of diesel. Even then diesel run pumps cost almost double the irrigation pumps run by electricity. Therefore, in nominal terms for the same amount of irrigation water the farmers who are using diesel are paying more for irrigation per ha than the farmers who are using electricity. I tested a further hypothesis whether increasing irrigation expenditure increases output for diesel users in a sub-sample of 260 households with no electricity connection. There is no evidence that increasing irrigation expenditure is leading to an output increase. This result further reinforces the issue of inefficiency in water use. This fact is also obvious from figure 1. For the same level of output per ha there is a range of irrigation expenditure per ha. From field research in the northwest region in December 2007 it has been found that diesel is costing one farmer 67 percent more in terms of energy expenditure than when he is using electricity for pumping the same amount of water. Then there is a difference in the capacity of pumps; newly installed and well maintained pumps are more energy efficient and cost effective than the old ones. High irrigation expenditure also captures the fact that the groundwater table is falling at many places like northwest and north central regions of Bangladesh even when farmers are pumping the same amount of water for irrigation per ha.

Figure 1. *Boro* rice output and irrigation expenditure per ha

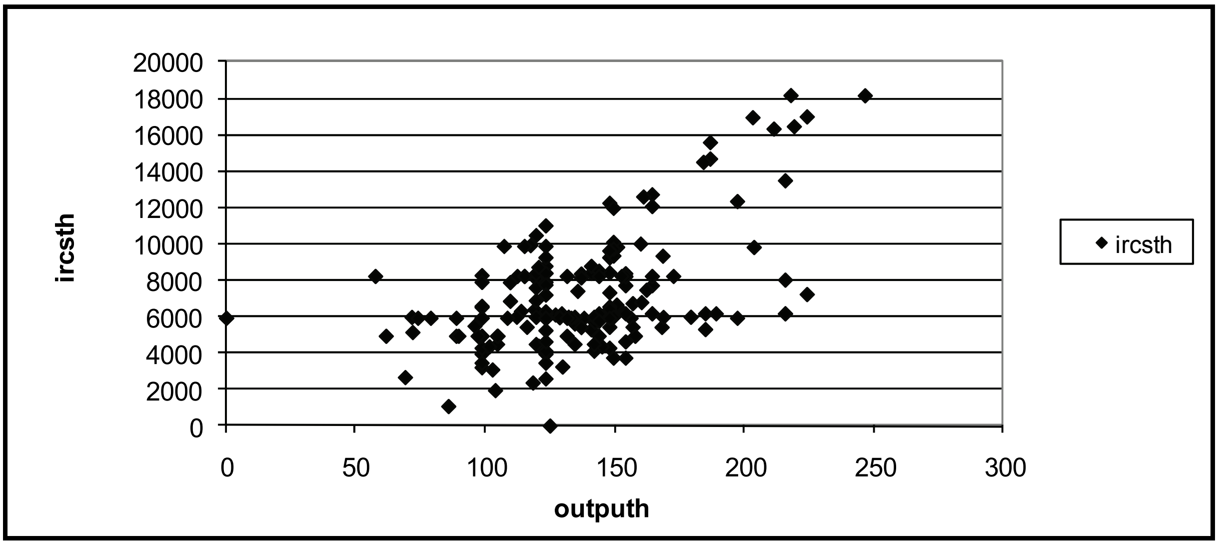


outputh = *boro* rice output (in maund) per ha, 1 maund = 37.32 kg in Bangladesh but in this dataset 1 maund was considered 40 kg, ircsth = irrigation expenditure in BDT per ha

Note: There are 16 farmers whose irrigation expenditure is 0. Local irrigation system has lowest irrigation expenditure for output per ha followed by canal irrigation system.

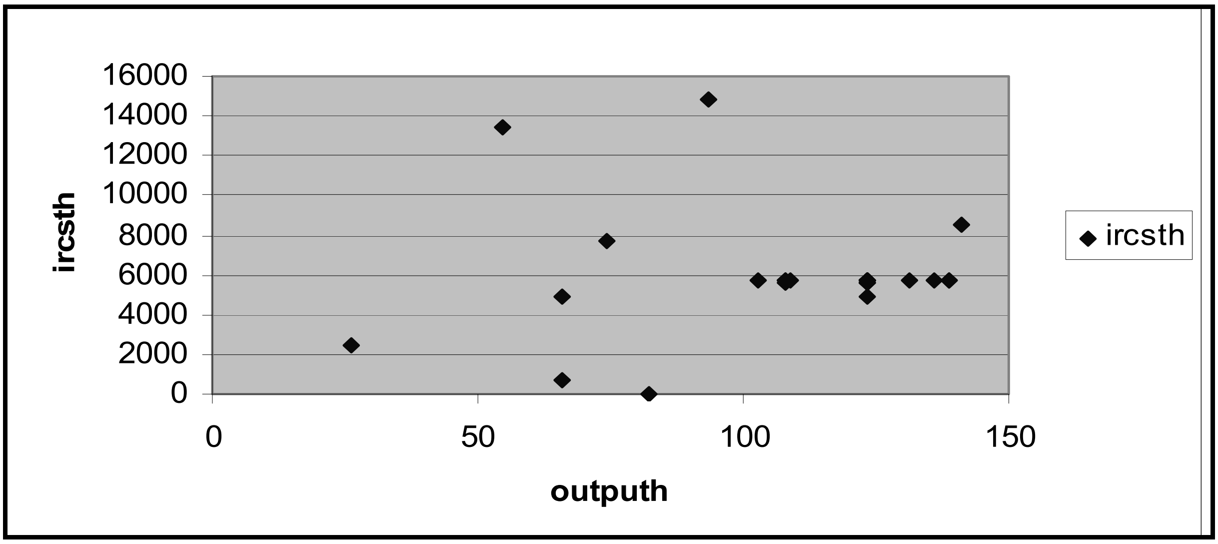
Source: own estimations

Figure 2. Output and irrigation expenditure per ha in water scarce region



Source: own estimations

Figure 3. Output and irrigation expenditure per ha in water surplus region



Source: own estimations

However, inefficiency is more likely in case of farmers who are using government owned DTW, public (canal) irrigation projects and traditional irrigation systems (which are much cheaper modes of irrigation than) compared to LLP, STW and privately owned DTW irrigation. As LLP and STW are privately owned these days hence more than 90 percent of irrigation done by LLP and STW can be considered private. In this sample 77 percent of irrigation is done by STW which is groundwater irrigation and has highest irrigation expenditure per ha. In the private sector some overuse of water may be due to the flat seasonal fee (i.e., zero marginal cost) resulting from the prevalence of one-fourth of the crop share being the payment method for irrigation expenditure at many places and due to indivisibility of shared tube well in some cases. High irrigation expenditure is also due to lack of recharge of groundwater level at many places during the dry season.

Therefore, Bangladeshi farmers are more efficient in land, labour, fertiliser use and ploughing with power tiller compared to irrigation water use. Medium land farmers are more efficient compared to highland, and very lowland farmers. Some conclusions and policy recommendations are made about the structure of *boro* rice production based on these results.

7. Conclusions and policy recommendations

In this paper I have examined the relative efficiency of input use in Bangladesh agriculture. Efficiency of input use is determined as comparison between marginal products of various inputs. I have imposed and tested restrictions on the translog production function in order to identify the appropriate technology used in *boro* rice production of Bangladesh. An unrestricted form of the translog technology is found to be the appropriate functional form for *boro* rice.

The empirical results suggest that *boro* rice output is significantly higher on medium land compared to very low and high land. An increase in irrigation expenditure in northeast, eastern hills and southeast regions has a negative impact on output. Overall output increases significantly when the amount devoted to power tiller and irrigation is jointly doubled. Therefore, *boro* rice production would increase with mechanisation of agriculture, land size, labour, fertilizer and increased irrigation. However, the elasticity of *boro* rice output is very low with respect to change in irrigation expenditure alone.

In terms of relative efficiency of input use this study shows that Bangladeshi farmers are least efficient in irrigation water management compared to land, labour, power tiller and fertiliser use. From field research and the extant literature it is evident that the main source of inefficiency is the high nominal price of diesel. As a result farmers who are using diesel instead of electricity are incurring higher irrigation expenditure for the same amount of irrigation water per ha and are expenditure inefficient relative to farmers who are using electricity. Second there is a 40 percent variation in monthly wages of pump mechanics as established from field research cited above. Not all pumps have the same level of efficiency. Lowering of groundwater table at many places in Bangladesh also cost farmers more in terms of energy expenditure for pumping the same amount of irrigation water.

The low efficiency might also be a manifestation of average prices of irrigation water paid by water user groups in case of surface water irrigation projects handed over by BWDB. Although farmers using STW and LLP are mostly privately owned and are efficient compared to farmers using canal irrigation projects and government owned DTW, some of them may be using more water than required due to indivisibility of shared tube well. But this is subject to further research. One-fourth of crop share as a payment method for irrigation water at many places also gives rise to a flat seasonal fee (marginal cost being zero) and overuse of water in many cases.

These findings are very important in the context of food inflation and high input prices. Increasing diesel price is increasing expenditure on irrigation, cultivation as well as food prices. In any case since *boro* rice production requires a lot of water as an input, the results from this study suggest that farmers must increase efficiency in irrigation water allocation to *boro* rice production. Hence, agricultural extension will play a very important role. Introduction of rice varieties that require less water for irrigation per ha is deemed mandatory. Government should give incentives or price support for wheat and maize production so that farmers diversify towards these crops that require much less water per ha for irrigation compared to *boro* rice. In order to run the pumps with electricity, stability in power supply is a must that will reduce irrigation expenditure as well as cultivation expenses drastically. In this endeavour there is no alternative to 100 percent rural electrification. But farmers must be charged full price for using electricity in order to pump water for irrigation. However, in order to induce efficient use farmers must be encouraged to pay marginal prices for maintenance and cost recovery of public irrigation projects.[6]

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