WORKING PAPER

The Relative Efficiency of Water Use in Bangladesh Agriculture

No. 49-10

Nasima Tanveer Chowdhury

SANDEE

South Asian Network for Development and Environmental Economics

June 2010

The Relative Efficiency of Water Use in Bangladesh Agriculture

Nasima Tanveer Chowdhury

Department of Economics, Gothenburg University
Gothenburg, Sweden

June 2010

South Asian Network for Development and Environmental Economics (SANDEE)
PO Box 8975, EPC 1056
Kathmandu, Nepal

SANDEE Working Paper No. 49-10

Published by the South Asian Network for Development and Environmental Economics (SANDEE)
PO Box 8975, EPC 1056 Kathmandu, Nepal.
Telephone: 977-1-5003222 Fax: 977-1-5003299

SANDEE research reports are the output of research projects supported by the South Asian Network for Development and Environmental Economics. The reports have been peer reviewed and edited. A summary of the findings of SANDEE reports are also available as SANDEE Policy Briefs.

National Library of Nepal Catalogue Service:

Nasima Tanveer Chowdhury
The Relative Efficiency of Water Use in Bangladesh Agriculture
(SANDEE Working Papers, ISSN 1893-1891; 2010- WP 49)

ISBN: 978 - 9937 -8218 - 7 - 2

Key words:

1. Relative Efficiency
2. Marginal Product
3. Production Function
4. Irrigation Water
5. *Boro* Rice
6. Bangladesh Agriculture

The South Asian Network for Development and Environmental Economics

The South Asian Network for Development and Environmental Economics (SANDEE) is a regional network that brings together analysts from different countries in South Asia to address environment-development problems. SANDEE's activities include research support, training, and information dissemination. Please see www.sandeeonline.org for further information about SANDEE.

SANDEE is financially supported by International Development Research Center (IDRC), The Ford Foundation, Swedish International Development Cooperation Agency (SIDA), the World Bank and the Norwegian Agency for Development Cooperation (NORAD). The opinions expressed in this paper are the author's and do not necessarily represent those of SANDEE's donors.

The Working Paper series is based on research funded by SANDEE and supported with technical assistance from network members, SANDEE staff and advisors.

Technical Editor
Mani Nepal

English Editor
Carmen Wickragamage

Comments should be sent to Nasima Tanveer Chowdhury, Department of Economics, Gothenburg University, Gothenburg, Sweden. Email: nasima.chowdhury@economics.gu.se

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

APPENDICES

Abstract

This study examines the marginal productivity of water and other inputs in dry season rice production in Bangladesh. Agriculture is the major water using sector in Bangladesh, but water is in short supply during the dry winter months. The study aims to understand how efficiently irrigated water is used in dry rice production. It estimates a translog production function for *boro* rice in seven hydrological regions and derives the marginal products of various inputs. These estimates are based on data collected by the International Rice Research Institute from a nationally representative sample of farm households in Bangladesh. The findings suggest that irrigation water is quite in-efficiently used in Bangladesh agriculture, particularly in comparison with other outputs. Various policies are recommended for increasing water use efficiency.

Key Words: Relative efficiency, Marginal product, Production function, Irrigation water, *Boro* rice, Bangladesh agriculture.

JEL Classification: Q13, Q25

The Relative Efficiency of Water Use in Bangladesh Agriculture

Nasima Tanveer Chowdhury

1. Introduction

Water scarcity for agricultural use in Bangaldesh is both seasonal and region-specific. Water is most scarce in the southwestern and northwestern regions of the country during the dry season due to low annual rainfall. The demand for both surface and groundwater for irrigation is on the rise in the dry winter season and amounts to 58.6 percent of the total demand for water (GOB, 2005). The principal crop during this season is *boro* rice, which is 70 percent of the total crop production of Bangladesh (GOB, 2005). Moreover, it requires more water in the production process than either wheat or potato. According to an estimate by Biswas and Mandal (1993), water requirements are 11,500m^3 per hectare (ha) of Boro rice. This paper examines whether water use is efficient in rice production in Bangladesh.

There are many government-run canal irrigation projects in the country. Between 1944 and 1999, the Bangladesh Water Development Board (BWDB) spent more than US$1700m on flood control drainage irrigation (FCDI) projects (WB, 2000). But 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, is not as functional as it should be. At present, the public sector is therefore responsible for maintaining only the surface water irrigation projects, which contribute about 10 percent of the total irrigation. Groundwater is the major source of irrigation, which is managed privately using minor irrigation devices.

The overall aim of the study is to examine whether farmers allocate irrigation water efficiently in dry-season rice production in Bangladesh. The specific research objectives are to estimate the marginal value product of water and to compare it with the marginal returns of other inputs in *boro* rice production. We test whether returns to factor inputs are equal using Bangladeshi data for *boro* rice (dry season rice). Since food security and employment generation are still major developmental challenges for Bangladesh, this study would have important policy implications for irrigation water use and crop production in agriculture. The marginal value estimates could be a basis for efficient water allocation. For instance, the lack of marginal pricing may be one of the major factors responsible for policy failure of the BWDB.

In this study, we estimate *boro* rice production function using cross-section data collected by the International Rice Research Institute (IRRI) on expenditures incurred in connection with agricultural inputs and the returns on investment from a nationally representative sample from 62 villages in Bangladesh. This is a very rich data set in the context of developing countries, particularly in terms of information on the returns of different types of agricultural labour and other inputs. We estimate elasticities of output with respect to various inputs and marginal products.

The next section presents a review of various studies on the efficiency of input uses. The third section gives a brief description of the study area. Section four discusses the data and the variables used. The fifth section discusses research methods, econometric issues and the hypotheses the study intends to test. In the sixth section, we discuss the estimated results. The final section concludes with some policy recommendations.

2. Efficiency of Input Use

Most studies on the efficiency of input base themselves on production function estimates. The studies undertaken in connection with Indian agriculture measure the absolute efficiency of water use (Vaidyanathan, 2004). Somanathan and Ravindranath (2006) estimated the marginal value of groundwater in Indian agriculture on the basis of actual water trade in the state of Andhra Pradesh (AP) while Banerji *et al.* (2006) studied the efficiency of groundwater use for sugarcane in North India using 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 expenditures. He also estimated 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 indicating that the two types of labour cannot be aggregated.

In a separate study, Jacoby (1993) estimated shadow wages for men, women, and children using data from the Peruvian highlands. Results from the translog production function indicate that OLS estimates were more efficient than the IV estimate. The present study finds an unrestricted translog function to be a better specification than the Cobb-Douglas function for *boro* rice production in Bangladesh.

In Bangladesh, the literature on testing the allocative efficiency of inputs in agriculture is very thin. Chowdhury (2005) estimated the high economic value of water in the southwest, southeast and northwest regions of Bangladesh. In the context of developing countries, a study that Linde-Rahr (2005) has undertaken for Vietnam is also important, which tested the relative efficiency of input use in agriculture. He assumed risk-neutral households and examined the ability of households to allocate factor inputs efficiently within the household. His results suggest that within households efficiency does indeed hold. Linde-Rahr maximised a joint profit function which included two production functions for rice and sugarcane. He used a seemingly unrelated regression (SUR) technique for estimation assuming that inputs are substitutable between these crops. If risk profiles across activities differ, he anticipated that inefficiencies and differences in factor returns would exist. According to his study, market failures due to asymmetric information could also lead to inefficient resource allocation. The major methodological difference between Linde-Rahr (2005) and the present study is that we estimate a single equation production function for *boro* rice in order to estimate the marginal productivity of water and other inputs for the seven hydrological regions of Bangladesh and assess whether the marginal value product varies significantly among them. We estimate a translog production function where the dependent variable is the value of the *boro* rice output.

3. Study Area

Bangladesh has seven hydrological regions (see Figure1). Agriculture is the major water-using sector while rice cultivation is the single most important activity in the economy. The crop calendar of Bangladesh patterns itself on the temporal distribution of rainfall and temperature throughout the year. There are three primary cropping seasons: pre-monsoon, monsoon and winter (dry season). *Aus* is the pre-monsoon rice variety, a*man* the rain-fed monsoon (wet season) rice variety and *boro* (irrigated) the dry season rice variety. *Boro* is the leading rice crop contributing about 55 percent of the total rice production followed by *aman* at 40 percent and *aus* at 5 percent (Bangladesh Bureau of Statistics, 2008). A remarkable feature of the rice growth pattern is the rising share of irrigated high yielding variety (HYV) *boro* rice. The other major crops are wheat, jute, sugarcane, oilseeds, pulses, potato, onion, spices and vegetables.

Rainfall characteristics dominate the precipitation pattern of Bangladesh, with rainfall dependent largely on the presence and the duration of the monsoon. The average annual rainfall varies from 1,200 mm in the extreme west to over 5,000 mm in the northeast (WB, 2000). Meteorologists have identified four seasons on the basis of rainfall patterns. About 80 percent of the total rainfall occurs during the monsoons from June to September. Only 10 percent of the annual rainfall is available during the combined post-monsoon (October - November) and winter (December - February) periods (WB, 2000). The rainfall is extremely unreliable in the subsequent pre-monsoon (March - May) period as well, which receives on average only 10 percent of the annual rainfall (WB, 2000).

Water shortage is regional as well as seasonal. Water is therefore very scarce in the southwest and northwest regions of Bangladesh during winter (December - February). The southwest region of Bangladesh, which has an inland zone and a coastal zone, is the Ganges-dependent region, which suffers from both dry season water shortage and arsenic contamination. In the coastal zone, the most shallow groundwater sources are saline while surface water salinity is also widespread. It also suffers from drainage congestion, salinity intrusion and high cyclone risks while also being the worst affected by arsenic contamination of groundwater. In inland areas, over time, the use of shallow tube wells (STW) for irrigation purposes has intensified.

The northwest region, on the other hand, is highly developed agriculturally and has the largest irrigated area of all regions supplied mainly by shallow tube wells. Due to STW irrigation, seasonal water table decline is widespread (Halcrow, 2001). The southern part of this region is however flood-prone. Therefore, it is home to some of the country's biggest flood control drainage and irrigation schemes. The northcentral region is the most industrialized and urbanized region of the country, which includes the capital city (Dhaka). This region too suffers from seasonal water table decline problems due to intensive STW irrigation.

In the eastern hills, irrigation is mainly by low lift pumps (LLP) since shallow tube well irrigation is limited due to groundwater salinity. The dry season flow also limits irrigation water availability. The southcentral region does not have the same dry season water shortage problem as the southwest region. But it is much more vulnerable to cyclones and storm surges in the coastal zone while also being prone to serious arsenic problems. Only the less saline area resorts to irrigation. Both LLP and STW are in use for irrigation. Because of the aquifer arsenic problems, the northeast region has relatively little exploitable shallow groundwater but has more abundant dry season surface water resources. Irrigation mostly depends therefore on low lift pumps than shallow tube wells (Halcrow, 2001).

4. Data and Variables

This paper uses data from an Agricultural Household Survey that the International Rice Research Institute (IRRI) conducted for three crop seasons in Bangladesh in 2004. It collected data on the expenditures of inputs (including irrigation water) and returns on investment from a nationally representative sample of farm households from 62 villages belonging to 57 of the 64 districts in Bangladesh. Our study uses a sub-sample of 724 farm households from seven regions that cultivated dry season *boro* rice in 2004.

Table 1 contains the descriptive statistics of *boro* rice production and related activities. The dependent variable is the value of rice output in BDT (Bangladesh Taka[1]). Ploughing expenditure consists of expenses on the power tiller and the wage bill for hired draught power. Labour days consist of both family and hired labour. Labour is mainly for ploughing, sowing, weeding, harvesting and threshing. Irrigation refers to total irrigation expenditure. 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 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 for water pumped from aquifers and groundwater. We measure seeds and fertilisers in kilogramme (kg). Expenditure data are available for pesticides and manure use. We measure land in ha. This includes both own and sharecropped land that farmers have devoted to *boro* rice cultivation. This is essentially a sample survey of very small farmers with an average plot size 0.16 ha. The average farm size in Bangladesh is 0.68 ha (Ahmad *et al*., 2001).

There are five 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 while clay loam has clay as a larger portion of the soil contents than other particles. Sand is light soil. We have categorized them into 3 categories according to clay contents: light, medium and heavy. Sandy loam is categorized as light, loamy as medium and clay loam as heavy soil.

Land in Bangladesh falls into four different categories. Land Type 1 is not flooded and is considered to be highland. Land Type 2 is medium land which is normally flooded up to about 90 cm (knee) in depth during the flood season. Land Types 3 and 4 are lowland and very lowland respectively. Lowland is land which is under chest-deep water during the months of August and September. Very lowland, on the other hand, remains under water for more than nine months of the year.

5. Methods

Our research question is whether dry season irrigation water use is efficient in Bangladesh. For efficiency, the value of the marginal physical product of water should be equal to its price. 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. It estimates the marginal physical productivity of inputs for each incremental application. The marginal value of each increment is the marginal physical product times the crop price.

[1] 1 USD = 58 BDT in 2004

We can estimate a number of different flexible functional forms including the translog form. We estimate both Cobb-Douglas and translog production functions. The translog production function however provides a greater variety of substitution possibilities than those restricted by the constant elasticity of substitution in the Cobb-Douglas function. We write the translog production function as:

$$\ln Y = \beta_0 + \sum_{i=1}^{n} \beta_i \ln x_i + \frac{1}{2}\left\{\sum_{i=1}^{n}\sum_{l=1}^{n} \beta_{il} \ln x_i \ln x_l\right\} + \sum^{k} \delta_k type_k + \sum^{h} \lambda_h land_h + \sum \gamma_r (\ln IH_r) + \mu \quad (1)$$

Where 1n Y = log of total value of *boro* rice production

1n x_i = log of i^{th} input use $i = 1,...,n.$ (including irrigation expenditure, I)

$type_k$ = irrigation type dummies (k = Low Lift Pump, Shallow and Deep tube wells)

$land_h$ = land type dummies (h: 3 elevation and 2 soil quality dummies)

1n IH_r = log of irrigation expenditure*regional dummies

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

We assume symmetry of cross product terms, that is $\beta_{il} = \beta_{li}$ (Greene, 2000), μ is a normally distributed random error, i.e. $\mu \overset{iid}{\sim} N[0, \sigma_u^2]$ We calculate the elasticity of output with respect to each factor of production by taking the partial derivative of output with respect to the factor under consideration. We derive the elasticity for irrigation water (I) as:

$$\varepsilon = \frac{\partial \ln Y}{\partial \ln I} = \beta_i + 2\beta_{ii} \ln x_i + \sum_{l \neq i} \beta_{il} \ln x_l + \gamma_i H_r \quad (2)$$

The marginal productivity of water is then:

(3)

$$\rho = \frac{\partial Y}{\partial I} = \frac{\partial \ln Y}{\partial \ln I} * \frac{Y}{I} = \varepsilon \frac{Y}{I} \quad (3)$$

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 then gives the marginal value of water for rice.

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

$$p^{rice} \frac{\partial f^{rice}}{\partial I^{rice}} = \omega \quad (4)$$

$$p^{rice} \frac{\partial f^{rice}}{\partial x_i^{rice}} = q_i \quad (5)$$

where p^{rice} is the price of rice, f^{rice} is the production function, I^{rice} is water used in rice. x_i^{rice} represents i^{th} input other than water and ω and q_is are water and i^{th} input prices respectively.

Hypotheses

In this section we discuss the expected signs on the coefficients of the explanatory variables included in the estimation of the production function. We present a summary in Table 2.

We expect all inputs, namely, land, ploughing expenditure, labour, seed, fertilizer, irrigation, manure and pesticides, to have a positive effect on output. We cannot predict the sign of the coefficients on the irrigation type variables (STW, DTW) a priori. Similarly, we cannot determine the sign of the coefficients of land of different elevations and soil quality which are dummy variables. The sign of irrigation expenditure in different hydrological regions are also unpredictable where there are six regional dummies for seven hydrological regions. We expect the doubling of all inputs, i.e., doubling each type of input expenditure in this model, to have a positive impact on output. However, we are not sure about the sign of the complementary inputs on output.

6. Results and Discussions

We outline the procedure followed in identifying the appropriate production function specification for *boro* rice in Appendix A1. The specification we prefer is a translog function as specified in equation (1). We report the results from the unrestricted translog production function in Table 3 which we discuss below. We correct the standard errors for heteroscedasticity.

The rise in irrigation expenditure in the northeast, the eastern hills and the southeast regions exert a negative impact on output. This increase in irrigation expenditure may be due to the increased energy cost, i.e., the use of diesel. Doubling the amount of irrigation expenses increases output significantly. The joint increase of labour and irrigation expenditure has a negative impact on output. However, the joint increase of seeds and irrigation expenses increases output. Both these inputs have a land augmenting effect on output.

Table 4 presents the elasticity of *boro* rice output with respect to the various inputs. The value of *boro* rice output is very inelastic in response to a change in all inputs including irrigation expenditure. The percentage increase in the value of *boro* rice output is only 1 percent of the increase in irrigation expenditure. This means that a 10% increase in irrigation expenditure leads to an increase in rice output of only 0.1%. As the information on actual water usage is not available, the increase in irrigation expenditure may not be due to an increase in the volume of irrigation water but from the use of diesel which is less efficient but is much more expensive than electricity. Therefore, it needs a substantial increase in irrigation expenditure to increase the value of output.

Marginal Return

We calculate marginal returns from these elasticity estimates which we report in Table 4. The marginal return on one ha land is BDT 18,320. The value of one ha land is BDT 11,425 which is one-third of the value of output. Therefore, land is very productive. The marginal return on ploughing with power tiller is BDT 3.44. That is one BDT increase in expenditure on ploughing with power tiller increases *boro* rice output by BDT 3.44. The marginal return on irrigation water is 0.05. The per BDT increase in irrigation expenditure raises output by only BDT 0.05. The marginal return on fertiliser is BDT 12.42 per kg. The average price of 1 kg fertiliser is BDT 10.04. We test the significance of the marginal returns, which we find to be significant at conventional levels (see Appendix A2 for details).

In general *boro* rice production requires three times more water than wheat or maize due to seepage and percolation in addition to evapo-transpiration for normal crop production.[2] The scientists at Bangladesh Rice Research Institute (BRRI) also found that farmers use more water than required as demonstrated from the experimental plots. Moreover, while there is a certain

[2] Personal communication with Dr A. Sattar, Director General (BRRI).

requirement of irrigation water for *boro* rice production, overuse will destroy the rice plants although water use below that level would result in less or no output per ha. The water requirement for irrigation also varies with soil moisture, temperature, annual rainfall and the *boro* rice variety.

Table 5 reports input and output price variations in terms of the coefficient of variation. In case of irrigation, ploughing, manure and pesticides, the variation represents variation in total expenditure. The quantity of physical inputs is not available except for seed and fertilizer. Expenditure is a proxy for the intensity of input use. If the unit price is fairly constant, an increase in expenditure implies a larger quantity of the input. Hence, these results would improve with better data. For instance, had we 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 either how much water the farmers use to irrigate their rice fields or the number of hours of irrigation pump use. The expenditure on irrigation consists of the volume of water used in the rice fields and the price per unit of irrigation water. The farmers in Bangladesh do not pay for using water as such; they pay instead for pumping water which is the expenditure on energy (fuel, diesel or electricity) and for hiring pump mechanics as and when required. Electricity and diesel cost 40 to 75 percent of the average variable cost of irrigation expenditure per ha[3] while the monthly wage of the pump mechanic is 25 to 60 percent of the total irrigation expenditure. There is a 40 percent variation in the monthly wages of pump mechanics.

In rural Bangladesh, due either to the lack of electricity in many villages and/or to frequent power outages, many farmers still depend on diesel for running their irrigation pumps. But there is a tax on diesel while the government subsidises electricity. Therefore, diesel-run pumps cost almost double the amount of irrigation pumps run by electricity. Hence, in nominal terms, for the same amount of irrigation water farmers who use diesel pay more per ha than those who use electricity. We tested a hypothesis on whether increasing irrigation expenditure increases output for diesel users in a sub-sample of 260 households who had no electricity connection. There was no evidence that increasing irrigation expenditure would lead to an increase in output. This result further reinforces the issue of inefficiency in water use. This fact is also evident in Figure 2. For the same level of output per ha, there is a range of irrigation expenditure per ha. There is difference in the capacity of pumps also, with newly installed and well-maintained pumps being more energy efficient and cost effective than old ones. High irrigation expenditure also captures the fact that the groundwater table is falling in many places, such as the northwest and the northcentral regions of Bangladesh, even when farmers are pumping the same amount of water for irrigation per ha.

However, we found inefficiency to be more likely in the 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 LLP, STW, and privately-owned DTW irrigation. However, since LLP and STW are now privately owned, we can consider more than 90 percent of irrigation using LLP and STW to be private. Farmers use STW for 77 percent of irrigation in our sample, which is groundwater irrigation that has the highest irrigation expenditure per ha. The overuse of water in the private sector may be due to some extent to the flat seasonal fee charged, one-fourth of the crop share being the payment method for irrigation expenditure at many places, and due to the indivisibility of use in the case of shared tube wells in some instances. The high irrigation expenditure is also because there is no recharge of the groundwater level at many places during the dry season.

---

3 Data from the author's field research.

Hence, Bangladeshi farmers are more efficient in their use of land, labour, fertiliser, and ploughing with power tiller than in their use of irrigation water. Moreover, medium land farmers are more efficient compared to the highland and very lowland farmers when it comes to irrigation water use. We arrive at some conclusions and policy recommendations on *boro* rice production based on these results below.

7. Conclusions and Policy Recommendations

In this paper, we have examined the efficiency of input use when it comes to *boro* rice production in Bangladesh agriculture. We determine efficiency of input use based on the marginal products of inputs. We have imposed and tested restriction on the translog production function in order to identify the appropriate technology for *boro* rice production in Bangladesh. We find an unrestricted form of the translog technology to be the most appropriate functional form for *boro* rice.

The empirical results suggest that an increase in irrigation expenditure in the northeast, the eastern hills and the southeast regions has a negative impact on output. Overall output increases significantly when the amount farmers devote to power tiller and irrigation is doubled. Therefore *boro* rice production would increase with mechanisation of agriculture, land size, labour, fertilizer and increased irrigation. However, our results show that the elasticity of *boro* rice output is very low with respect to changes in irrigation expenditure alone.

The low efficiency of water usage might be a manifestation of the average prices of irrigation water that user groups pay in cases of surface water irrigation projects that the BWDB has handed over to the users. Although farmers using privately-owned STW and LLP are more efficient compared to farmers using canal irrigation projects and government-owned DTW, some of them may be using more water than required due to the indivisibility of water use share in shared tube wells. However, it is a subject that requires further research. One-fourth of the crop share as a flat-fee payment method for irrigation water use at many places also results in overuse of water in many instances.

These findings are very important in the context of inflation in food and input prices. Increasing diesel prices are increasing expenditure on irrigation (diesel being the main fuel in irrigation) and cultivation as well as food prices. Moreover, since *boro* rice production requires a lot of water as an input, the results from this study underline the importance of farmers taking steps to increase efficiency in irrigation water allocation to *boro* rice production. Hence, agricultural extension activities would have to play a very important role in bringing about the optimum situation. It is mandatory to introduce rice varieties that require less water for irrigation per ha. Moreover, the government should give incentives or price support for wheat and maize production so that farmers would diversify crop production 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 the power supply is a must, which will reduce the expenditure on irrigation as well as the overall expense on cultivation drastically. In order to bring about this switch from diesel to electricity, there is no other alternative but 100 percent rural electrification. However, in order to guard against wastage, the government must charge farmers full price for using electricity in order to pump water for irrigation. Moreover, in order to maintain and to recover costs associated with public irrigation projects, the government must encourage farmers to pay marginal prices.

7. Acknowledgements

I would like to thank Karl-G ran M ler and Jean-Marie Baland for their invaluable comments at different stages of this paper. I am also grateful to Priya Shyamsundar, Programme Director, South Asian Network for Development and Environmental Economics (SANDEE), A. K. Enamul Haque, Syed M. Ahsan, E. Somanathan, Sir Partha Dasgupta, Thomas Sterner, Ingela Ternstrom, Mani Nepal and Ram C. Bhattarai for their comments and advice. I would like to record my appreciation of the research grant from SANDEE which enabled me to undertake this study. I express my sincere gratitude to the Economic Research Group (ERG) for hosting this grant. The usual disclaimers apply.

References

Ahmad, Q. K., A. K. Biswas, R. Rangachari and M. M. Sainju (eds.) (2001), *Ganges-Brahmaputra-Meghna Region: A Framework for Sustainable Development,* Dhaka, Bangladesh: University Press Limited.

Banerji, A. and J.V. Meenakshi (2006), 'Groundwater irrigation in India: institutions and markets', SANDEE Working Paper 19:06, SANDEE, Kathmandu.

Biswas, M. R. and M. A. S. Mandal (1993), *Irrigation Management for Crop Diversification in Bangladesh,* Dhaka, Bangladesh: University Press Limited.

Chowdhury, N. T. (2005), 'The economic value of water in the Ganges-Brahmaputra-Meghna River Basin', Beijer Discussion Paper 202, Beijer International Institute of Ecological Economics, Stockholm.

Available at www.beijer.kva.se/publications/pdf-archive/Disc202.pdf [accessed in October 2005]
Government of Bangladesh (2005), *National Strategy for Accelerated Poverty Reduction*, General Economics Division, Planning Commission and the Government of the People's Republic of Bangladesh, Dhaka, Bangladesh.

Greene, W.H. (2000), *Econometric Analysis*, 4th Edition, New Jersey: Prentice Hall.

Halcrow, W. (2001), *Draft National Water Management Plan*, Main Report, vol. 2, Dhaka, Bangladesh: Halcrow & Associates.

Hossain, M., D. Lewis, M. Bose and A. Chowdhury (2007), 'Rice research, technological progress and poverty: the Bangladesh case', in *Agricultural Research, Livelihoods, and Poverty: Studies of Economic and Social Impacts in Six Countries*, Baltimore, USA: The Johns Hopkins University Press.

Jacoby, H. G**.** (1992), 'Productivity of men and women and the sexual division of labor in peasant agriculture of the Peruvian Sierra', *Journal of Development Economics* 37: 265-287.

Jacoby, H. G**.** (1993), 'Shadow wages and peasant family labour supply: an econometric application to the Peruvian Sierra', *Review of Economic Studies* 60: 903-921.

Linde-Rahr, M. (2005), **'**Differences in agricultural returns: an empirical test of efficiency in factor input allocation using Vietnamese data', *Agricultural Economics* 32: 35-45.

Sadoulet, E. and A. De Janvry (1995), *Quantitative Development Policy Analysis*, Baltimore and London: Johns Hopkins University Press.

Somanathan, E. and R. Ravindranath (2006), 'Measuring the marginal value of water and elasticity of demand for water in agriculture', *Economic and Political Weekly* June 30: 2712-2715.

Vaidyanathan, A. (2004), 'Efficiency of water use in agriculture', *Economic and Political Weekly* 2989-2996.

Wang, H. and S. Lall (2002), 'Valuing water for Chinese industries: a marginal productivity analysis', *Applied Economics* 34: 759-765.

Wooldridge, J. M. (2003), *Introductory Econometrics: A Modern Approach*, 2nd Edition, Thomson, South-western.

World Bank (2000), 'Bangladesh: climate change and sustainable development', Bangladesh Report No. 21104-BD, Rural Development Unit, South Asia Region, World Bank, Washington D.C.

LIST of TABLES

Table 1: Agricultural Statistics for *Boro* Rice

Variables	Mean	Std. Dev.	Min	Max
Output (BDT/season)	5428	4537	250	45000
Plot size (ha)	0.16	0.12	0.01	1.03
Labour (days/season)	22	15	4	141
Irrigation expenses (BDT/season)	1157	1116	1	11001
Seeds (kg/season)	15	26	1	400
Fertilisers (kg/season)	57	47	1	401
Draft animals (BDT/season)	19	82	1	876
Power tiller (BDT/season)	284	265	1	2101
Pesticides (BDT/season)	93	126	1	2021
Manure expenses (BDT/season)	51	111	1	972
Shallow tube well	0.77	0.42	0	1
Deep tube well	0.03	0.16	0	1
Low land	0.21	0.41	0	1
Medium land	0.31	0.46	0	1
High land	0.28	0.45	0	1
Light soil	0.3	0.46	0	1
Heavy soil	0.49	0.5	0	1
H1 (Southcentral region)	0.08	0.28	0	1
H2 (Southeast region)	0.1	0.31	0	1
H3 (Eastern hills)	0.05	0.22	0	1
H4 (Northeast region)	0.04	0.19	0	1
H5 (Northcentral region)	0.21	0.41	0	1
H6 (Southwest region)	0.25	0.43	0	1

Table 2: List and Description of Variables

Variable	Definition	Expected Sign
loutput	log of value of boro rice output in BDT	dependent variable
lland	log of land in ha	(+)
ldraft	log of ploughing expenditure of draft animals in BDT	(+)
lpower	log of ploughing expenditure of power tiller in BDT	(+)
llabour	log of labour days	(+)
lseed	log of seeds in kg	(+)
lfertilizer	log of fertilizers in kg	(+)
lirrigation	log of irrigation expenditure in BDT	(+)
lmanure	log of manure expenditure in BDT	(+)
lpesticide	log of pesticide expenditure in BDT	(+)
shallow	a dummy variable which is 1if the irrigation type is shallow tube well and 0 otherwise	(?)
deep	a dummy variable which is 1if the irrigation type is deep tube well and 0 otherwise	(?)
mediumlland	medium land dummy * log of land	(?)
highlland	high land dummy * log of land	(?)
lowlland	low land dummy * log of land	(?)
lightland	light soil dummy * log of land	(?)
heavyland	heavy soil dummy * log of land	(?)
$lnIH_1$	log of irrigation expenditure * region 1 (southcentral) dummy	(?)
$lnIH_2$	log of irrigation expenditure * region 2 (southeast) dummy	(?)
$lnIH_3$	log of irrigation expenditure * region 3 (eastern hills) dummy	(?)
$lnIH_4$	log of irrigation expenditure * region 4 (northeast) dummy	(?)
$lnIH_5$	log of irrigation expenditure * region 5 (northcentral) dummy	(?)
$lnIH_6$	log of irrigation expenditure * region 6 (southwest) dummy	(?)
l2land	log of land* log of land	(+)
l2ldraft	log of ploughing expenditure of draft animals* log of ploughing expenditure of draft animals	(+)
l2lpower	log of ploughing expenditure of power tiller * log of ploughing expenditure of power tiller	(+)

l2lpower	log of ploughing expenditure of power tiller * log of ploughing expenditure of power tiller	(+)
l2labour	log of labour days * log of labour days	(+)
l2seed	log of seeds * log of seeds	(+)
l2fertilizer	log of fertilizers * log of fertilizers	(+)
l2irrigation	log of irrigation expenditure * log of irrigation expenditure	(+)
l2manure	log of manure expenditure * log of manure expenditure	(+)
l2pesticide	log of pesticide expenditure * log of pesticide expenditure	(+)
landdraft	log of land * log of ploughing expenditure of draft animals	(?)
landpower	log of land * log of ploughing expenditure of power tiller	(?)
landlabour	log of land * log of labour days	(?)
landseed	log of land * log of seeds	(?)
landfertilizer	log of land * log of fertilizers	(?)
landirrigation	log of land * log of irrigation expenditure	(?)
landmanure	log of land * log of manure expenditure	(?)
landpesticide	log of land * log of pesticide expenditure	(?)
draftpower	log of ploughing expenditure of draft animals* log of ploughing expenditure of power tiller	(?)
draftlabour	log of ploughing expenditure of draft animals* log of labour days	(?)
draftseed	log of ploughing expenditure of draft animals* log of seeds	(?)
draftfertilizer	log of ploughing expenditure of draft animals* log of fertilizers	(?)
draftirrigation	log of ploughing expenditure of draft animals* log of irrigation expenditure	(?)
draftmanure	log of ploughing expenditure of draft animals* log of manure expenditure	(?)
draftpesticide	log of ploughing expenditure of draft animals* log of pesticide expenditure	(?)
powerlabour	log of ploughing expenditure of power tiller* log of labour days	(?)
powerseed	log of ploughing expenditure of power tiller* log of seeds	(?)
powertfertilizer	log of ploughing expenditure of power tiller* log of fertilizers	(?)
powerirrigation	log of ploughing expenditure of power tiller* log of irrigation expenditure	(?)

powermanure	log of ploughing expenditure of power tiller* log of manure expenditure	(?)
powerpesticide	log of ploughing expenditure of power tiller* log of pesticide expenditure	(?)
labourseed	log of labour days* log of seeds	(?)
labourfertilizer	log of labour days* log of fertilizers	(?)
labourirrigation	log of labour days* log of irrigation expenditure	(?)
labourmanure	log of labour days* log of manure expenditure	(?)
labourpesticide	log of labour days* log of pesticide expenditure	(?)
seedfertilizer	log of seeds* log of fertilizers	(?)
seedirrigation	log of seeds* log of irrigation expenditure	(?)
seedmanure	log of seeds* log of manure expenditure	(?)
seedpesticide	log of seeds* log of pesticide expenditure	(?)
fertilizerirrigation	log of fertilizers* log of irrigation expenditure	(?)
fertilizermanure	log of fertilizers* log of manure expenditure	(?)
fertilizerpesticide	log of fertilizers* log of pesticide expenditure	(?)
irrigationmanure	log of irrigation expenditure* log of manure expenditure	(?)
irrigationpesticide	log of irrigation expenditure* log of pesticide expenditure	(?)
manurepesticide	log of manure expenditure * log of pesticide expenditure	(?)

Table 3: Unrestricted Translog Production Function Estimates for *Boro* Rice

Variable	Definition	Coefficient	t-statistics
ldraft	log of ploughing expenditure of draft animals in BDT	-0.39***	-4.07
lpower	log of ploughing expenditure of power tiller in BDT	0.48***	3.69
llabour	log of labour days	3.02***	8.39
lfertilizer	log of fertilizers in kg	-1.24***	-3.35
lirrigation	log of irrigation expenditure in BDT	0.13	1.38
mediumlland	medium land dummy * log of land	0.06***	4.21
$lnIH_2$	log of irrigation expenditure * region 2 (southeast) dummy	-0.02***	-3.14
$lnIH_3$	log of irrigation expenditure * region 3 (eastern hills) dummy	-0.02***	-2.53
$lnIH_4$	log of irrigation expenditure * region 4 (northeast) dummy	-0.03***	-2.89
$lnIH_6$	log of irrigation expenditure * region 6 (southwest) dummy	-0.01*	-1.72
l2lpower	log of ploughing expenditure of power tiller * log of ploughing expenditure of power tiller	0.02**	2.08
l2labour	log of labour days * log of labour days	-0.23***	-5.87
l2fertilizer	log of fertilizers * log of fertilizers	0.12***	3.31
l2irrigation	log of irrigation expenditure * log of irrigation expenditure	0.02***	3.83
landdraft	log of land * log of ploughing expenditure of draft animals	-0.08***	-3.05
landpower	log of land * log of ploughing expenditure of power tiller	0.09***	3.78
landlabour	log of land * log of labour days	0.32***	4.84
l2fertilizer	log of fertilizers * log of fertilizers	0.12***	3.31
l2irrigation	log of irrigation expenditure * log of irrigation expenditure	0.02***	3.83
landdraft	log of land * log of ploughing expenditure of draft animals	-0.08***	-3.05
landpower	log of land * log of ploughing expenditure of power tiller	0.09***	3.78
landlabour	log of land * log of labour days	0.32***	4.84
labourirrigation	log of labour days* log of irrigation expenditure	-0.08**	-2.37
seedirrigation	log of seeds* log of irrigation expenditure	0.01*	1.85
Constant		4.31***	11.78
Adj. R^2		0.84	
Number of observations		724	

***, ** and *represent significance of parameters at 1, 5 and 10 percent level respectively.
This table presents significant results only.

Table 4: Yield Elasticities for Boro rice and Marginal Returns to Inputs

Input	Elasticity	Marginal Return
Land	0.54	18,319.97
Very low land	0.54	19,270.61
Medium land	0.6	19,846.16
High land	0.59	18,795.94
Labour	0.21	52.41
Ploughing with power tiller	0.18	3.44
Irrigation	0.01	0.05
Fertiliser	0.13	12.42

Note: Marginal returns are at Sample Mean in BDT

Table 5: 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

Note: The numbers present coefficients of variation.

LIST of FIGURES

Figure 1: Hydrological Regions of Bangladesh

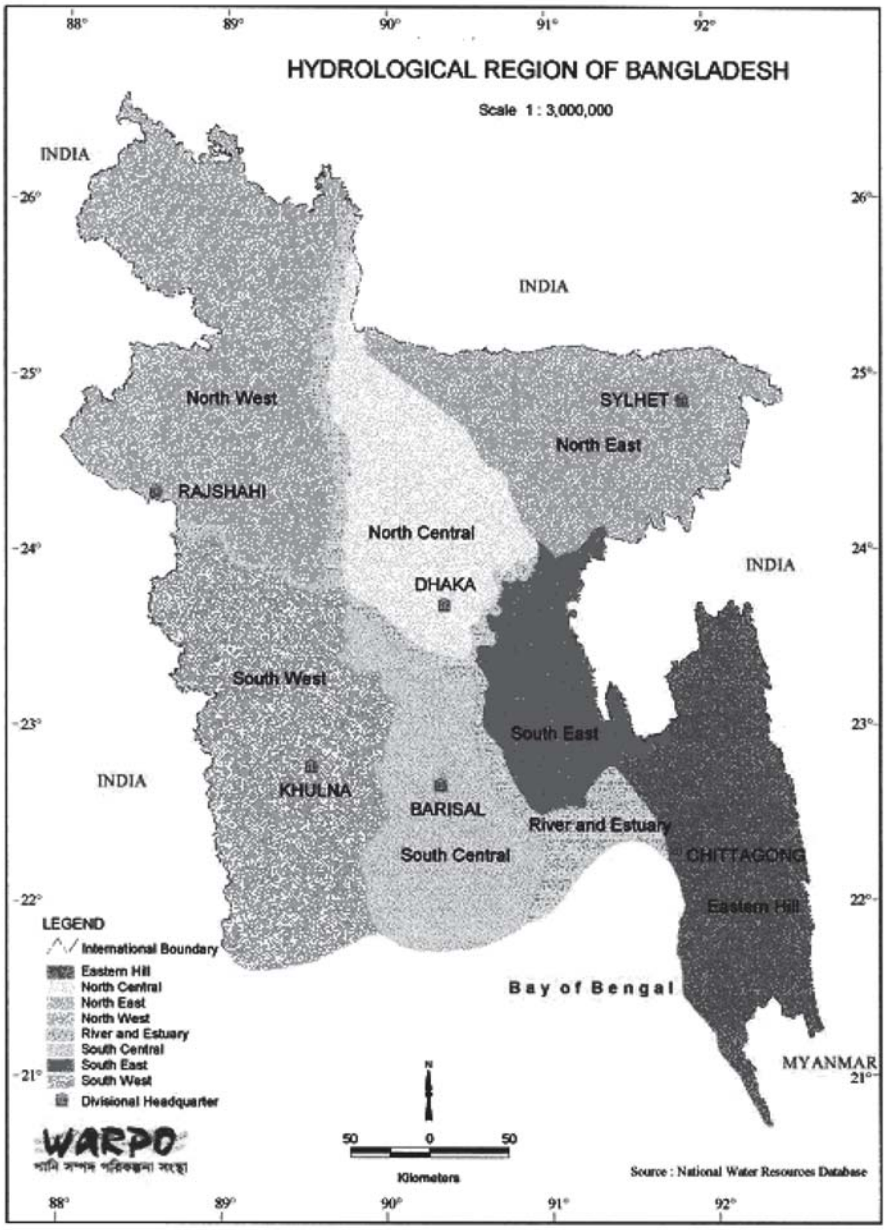
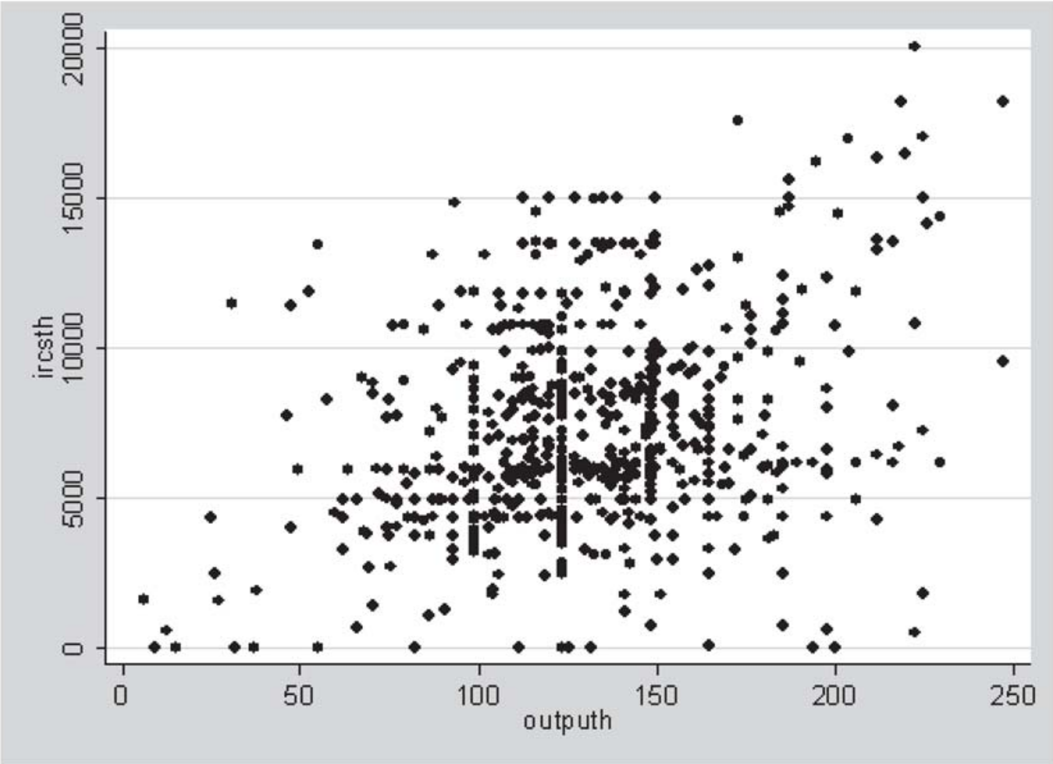


Figure 2: ***Boro*** Rice Output and Irrigation Expenditure Per ha



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 the lowest irrigation expenditure for output per ha followed by canal irrigation system.

Figure 3: Output and Irrigation Expenditure per ha in Water Scarce Region

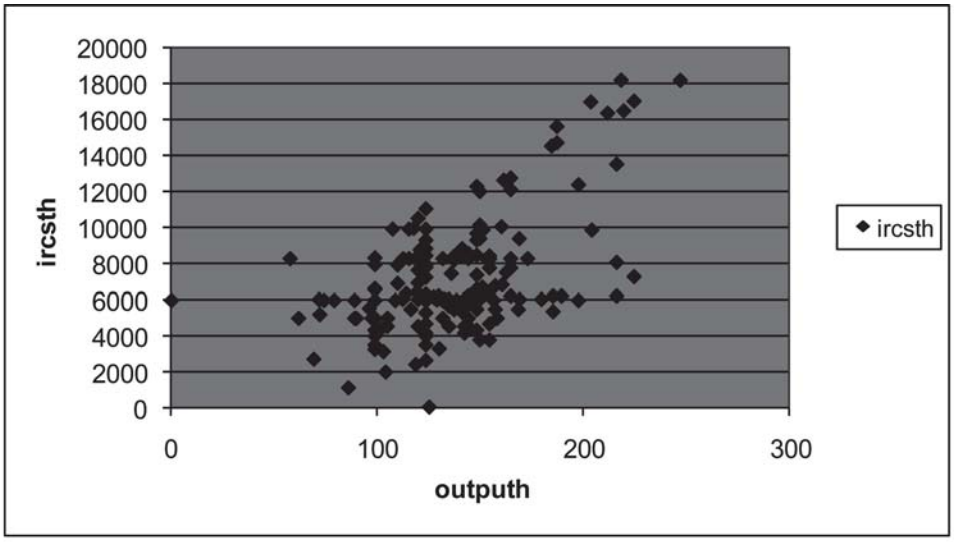
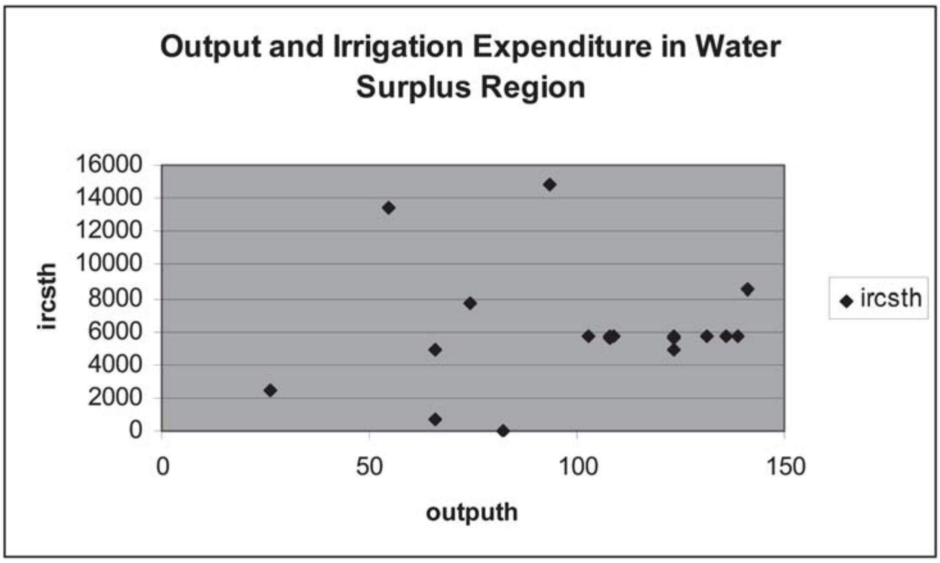


Figure 4: Output and Irrigation Expenditure per ha in Water Surplus Region



APPENDICES

Appendix A1: Model Selection

The dependent variable is the value of rice output in BDT. We first estimate an unrestricted translog function. Several of the coefficients in this unrestricted translog function were not significant at conventional levels. Therefore, we impose restrictions and estimate the restricted function without the second-order and cross product terms

$$\beta_{ii} = \beta_{il} = \beta_{li} = 0 \qquad \forall \text{ i, l}$$

This in essence is a Cobb-Douglas production function:

$$\text{(A1.1)} \qquad \ln Y = \beta_0 + \sum_{i=1}^{n} \beta_i \ln x_i + \sum^{k} \delta_k type_k + \sum^{h} \lambda_h land_h + \sum \gamma_i (\ln IH_r) + \mu$$

We then conduct the F-test to determine the appropriate function.

$$\text{(A1.2)} \qquad F = \frac{\dfrac{R_u^2 - R_r^2}{j}}{\dfrac{1 - R_u^2}{N - K}} \sim F_{j,N-K},$$

where R_u^2 = R^2 from the unrestricted (translog) function
R_u^2 = R^2 from the restricted (Cobb-Douglas) function
j = the number of restricted parameters
N = the number of observations
K = the number of estimated parameters in the translog

The calculated F statistic $= \dfrac{\dfrac{0.85 - 0.81}{16}}{\dfrac{1 - 0.85}{698}} = 11.63$

The critical value $F_{16, 698}$ is somewhere between 2.32 and 2.47 at 1 percent level of significance. Since the calculated F statistic is greater than this critical value, we reject the hypothesis that all the coefficients on the second order and cross product terms are zero. The preferred specification is therefore:

(1)

$$\ln Y = \beta_0 + \sum_{i=1}^{n} \beta_i \ln x_i + \frac{1}{2}\left\{\sum_{i=1}^{n}\sum_{l=1}^{n} \beta_{il} \ln x_i \ln x_l\right\} + \sum^{k} \delta_k type_k + \sum^{h} \lambda_h land_h + \sum \gamma_i (\ln IH_r) + \mu$$

Appendix A2: Test for Significance of Marginal Return of Inputs

Significance of Marginal Return on Land

testnl((_b[landdraft]*0.43+_b[landpower]*4.83+_b[landlabour]*2.91+_b[landfertilizer]*3.79) *(5428.14/0.16))=0

(1) ((_b [landdraft]*0.43+_b [landpower]*4.83+_b [landlabour]*2.91+_b [landfertilizer]*3.79)
*(5428.14/0.16)) = 0

F (1, 698) = 57.65
Prob > F = 0.00

Significance of Marginal Return on Very Low Land

testnl((_b[landdraft]*0.43+_b[landpower]*4.83+_b[landlabour]*2.91+_b [landfertilizer]*3.79) *(6780.4/0.19))=0

(1) ((_b [landdraft]*0.43+_b [landpower]*4.83+_b

Significance of Marginal Return on Medium Land

testnl((_b[mediumlland]+_b[landdraft]*0.43+_b[landpower]*4.83+_b[landlabour]*2.91+_b [landfertilizer]*3.79)*(4961.54/0.15))=0

(1) ((_b [mediumlland]+_b[landdraft]*0.43+_b[landpower]*4.83+_b[landlabour]*2.91 +_b [landfertilizer]*3.79)*(4961.54/0.15)) = 0

F (1, 698) = 63.67
Prob > F = 0.00

Significance of Marginal Return on High Land

testnl((_b[highlland]+_b[landdraft]*0.43+_b[landpower]*4.83+_b[landlabour]*2.91+_ b[landfertilizer]*3.79)*(4778.63/0.15))=0

(1) ((_b [highlland]+_b[landdraft]*0.43+_b[landpower]*4.83+_b[landlabour]*2.91 +_b [landfertilizer]*3.79)*(4778.63/0.15)) = 0

F (1, 698) = 59.95
Prob > F = 0.00

Significance of Marginal Return on Labour

testnl((_b[llabour]+_b[l2labour]*5.82+_b[landlabour]*(- 2.04)+_b[powerlabour]*4.83 +_b[labourirrigation]*6.63)*(5428.14/21 .75))=0

(1) ((_b [llabour] +_b [l2labour]*5.82+_b [landlabour]*(-2.04) +_b [powerlabour]*4.83 +_b [labourirrigation]*6.63)*(5428.14/21.75)) = 0

F (1, 698) = 21.25
Prob > F = 0.00

Significance of Marginal Return on Power Tiller

testnl((_b[lpower]+_b[l2lpower]*9.66+_b[landpower]*(-2.04)+_b[powerlabour]*2.91 +_b[powerseed]*2.32+_b[powerirrigation]*6.63)*(5428.14/283.58)) =0

(1) ((_b [lpower] +_b [l2lpower]*9.66+_b [landpower]*(-2.04) +_b[powerlabour]*2.91 +_b [powerseed]*2.32+_b [powerirrigation]*6.63)*(5428.14/283.58)) = 0

F (1, 698) = 9.91
Prob > F = 0.00

Significance of Marginal Return on Fertiliser

testnl((_b[lfertilizer]+_b[l2fertilizer]*7.58+_b[landfertilizer]*(-2.04)+_b[draftfertilizer]*0.43)*(5428.14/56.79)) =0

(1) ((_b [lfertilizer] +_b [l2fertilizer]*7.58+_b [landfertilizer]*(-2.04) +_b [draftfertilizer]*0.43) *(5428.14/56.79)) = 0

F (1, 698) = 4.62
Prob > F = 0.03

Significance of Marginal Return on Irrigation

testnl((_b[lirrigation]+_b[$lnIH_2$]+_b[$lnIH_3$]+_b[$lnIH_4$]+_b[$lnIH_6$]+_b[l2irrigation]*13.26 +_b [powerirrigation]*4.83+_b [labourirrigation]*2.91+_b [seedirrigation]*2.32)*(5428.14/1155.69)) =0

(1) ((_b[lirrigation]+_b[$lnIH_2$]+_b[$lnIH_3$]+_b[$lnIH_4$]+_b[$lnIH_6$]+_b[l2irrigation]*13.26 +_b [powerirrigation]*4.83+_b [labourirrigation]*2.91+_b [seedirrigation]*2.32) * (5428.14/1156.69)) = 0

F (1, 698) = 3.85
Prob > F = 0.05

Appendix A3

Table A3.1: Correlation between Inputs

	lland	ldraft	Lpower	Labour	lseed	lfertiliz-er	lmanu-re	lirrigatio-n	lpesticide
lland	1								
ldraft	0.04	1							
lpower	0.22	-0.35	1						
llabour	0.83	-0.1	0.23	1					
lseed	0.73	0.06	0.18	0.66	1				
lfertilizer	0.79	-0.08	0.37	0.75	0.62	1			
lmanure	0.05	0.03	-0.07	0.001	0.01	0.02	1		
lirrigation	0.41	-0.13	0.38	0.44	0.31	0.55	0.02	1	
lpesticide	0.3	-0.07	0.19	0.31	0.28	0.38	-0.03	0.13	1

Table A3.2: Restricted Cobb-Douglas Production Function Estimates for *Boro* Rice

Variable	Coefficient	t-statistics
Lland	0.63***	8.48
Lpower	0.05***	5.14
Labour	0.26***	3.48
Lirrigation	0.07***	2.69
Mediumlland	0.05***	3.91
highlland	0.05***	3.75
lnIH2	-0.02***	-3.23
lnIH3	-0.03***	-2.93
lnIH4	-0.02**	-2.18
Constant	8.28***	17.67
Adj. R2	0.81	
Number of observations	724	

*** and ** represent significance of parameters at 1 and 5 percent level respectively. The table presents significant results only.

Table A3.3: Elasticity and Marginal Return Estimates from Cobb-Douglas Production Function

Input	Elasticity	Marginal Return in BDT
Land	0.63	21, 373.3
Very lowland	0.63	22, 482.38
Medium land	0.68	22, 492.31
High land	0.68	21, 663.12
Labour	0.26	64.89
Ploughing with power tiller	0.05	0.96
Irrigation	0.07	0.33
Irrigation in Northwest region	0.07	0.33
Irrigation in Northeast region	0.05	0.22
Irrigation in Eastern hills	0.04	0.26
Irrigation in Southeast region	0.05	0.24

SANDEE Sponsors

ICIMOD

NORAD

Sida

Swedish International Development
Cooperation Agency

IDRC CRDI

International Development Research Centre

Centre de recherches pour le développement international

SANDEE

South Asian Network for Development and Environmental Economics

SANDEE
PO Box 8975 EPC 1056
Kathmandu, Nepal

Tel: 977-1-5003222
Fax:977-1-5003299
E-mail: info@sandeeonline.org
Website: www.sandeeonline.org

9789937821872