4

IMPROVING AGRICULTURAL EFFICIENCY AMONGST GROUNDWATER USERS: THE CASE OF SUGARCANE IN NORTH INDIA*

Gauri Khanna

This paper estimates inequities in production and income for different categories of water users in the context of a rapidly depleting resource by estimating technical inefficiency using frontier techniques. The research is based on primary survey data from a North Indian village that shares characteristics commonly observed in other groundwater-dependant agricultural areas. Estimated technical efficiency scores are highest on plots where water is sourced from a privately owned tubewell, followed by plots serviced by partnered tubewells and lowest on plots where water is bought. Income gains from improved efficiency follow the reverse patterns with the largest gains of Rupees (Rs) 1082 per *bigha*[1] estimated for buyers' plots and Rs. 649 per bigha for plots with their own tubewell with the average of Rs. 867 for all plots. A policy package of improved power, joint ownership of tubewells, farmer training and better water transportation systems are prescribed as policy measures to alleviate the differences amongst water users.

INTRODUCTION

Since independence, India's gross irrigation potential has increased nearly five-fold and foodgrain production has quadrupled (Government of In-

---

Gauri Khanna is a PhD Candidate in International Economics at the Graduate Institute of International Studies, Geneva (khanna1@hei.unige.ch).

dia 2002) transforming the nation from food deficiency to food surplus. Between 70 and 90 percent of available water in India is used to meet the irrigation needs of the country, leaving the remainder for industry and the domestic sector. The utilisation of groundwater sources has played a key role in altering the agricultural profile and in achieving food security. Groundwater development has largely been through private initiative and has grown at an alarming pace; for example, in Uttar Pradesh, net irrigated area by private tubewells grew from 48 thousand hectares in 1960-61 to 5095 thousand hectares in 1984-85 (Le Moigne et al. 1992). This rapid expansion has been supported by measures such as rural electrification programs and availability of credit. Further, the advantages of secure and controlled access proffered by investment in improved groundwater extraction devices, and a shift to the production of water-intensive crops such as sugarcane and paddy, has led to a surge in tubewells. The lack of any concrete laws on groundwater in India, which essentially allows anyone owning land to have unlimited access to the water beneath it, provides an added incentive to construct tubewells. The distortion in groundwater markets produced by subsidized electricity and diesel oil has led to over-extraction of water; for the resource, this means a decline in water tables and a threat to its sustainability and to the viability of agricultural production.

Research Objectives

While increasing productivity of all agricultural inputs at the farm level is a worthy goal, the indispensability of water to the agricultural sector makes its efficient use essential to meet India's consumption demands imposed by an expanding population and a growing economy. This paper uses primary survey data to look at technical efficiency in sugarcane production, a water-intensive crop, across a cross section of farmers and by category of water users in the north Indian state of Uttar Pradesh. The analysis is completed by an examination of water markets, of water use patterns, and of water exchange amongst farmers. The study of water is particularly relevant for the sugarcane crop, which is a comparatively lucrative crop widely grown in the North Indian agricultural belt.[2]

The structure of water markets allows an analysis of how groundwater is exchanged between farmers. There are several arrangements observed in the field for access to water. The most desirable is the independent ownership of a tubewell, which permits controlled access to water for cultivating private plots. A second arrangement is the joint ownership of tubewells, where ownership is split amongst partners, often between brothers. The third category of farmers is those who buy surplus water from owners of neighbouring tubewells. This paper finds technical efficiency to be the lowest on purchased water plots followed by those serviced by jointly owned tubewells. Based on our findings, I recommend a policy package for the improvement in the existing power and water infrastructure as well as incentives to foster joint ownership of tubewells.

The benefits to private ownership over shared arrangements and water buying include timeliness of water delivery as well as higher yields and profits. The privileges conferred by access to water are expected to influence the efficiency of sugarcane production arising from the interaction of water resources with other inputs. Further, these privileges permit indiscriminate water use by owners. This excessive use arises largely from the low operating costs of running a tubewell, which are caused by subsidized electricity charges and flat rate charges, a common government policy for the agricultural sector. While joint ownership is preferable to buying water, it lacks the direct control and access to water enjoyed under single tubewell ownership as water must be distributed amongst partners starting with the highest investor in the tubewell. With interruptions in the electricity supply, this pattern gets disrupted and affects the smaller shareholders the most with respect to the timing of irrigation. Thus, patterns of water use are expected to vary across farmers - between buyers of water and those who *own* their water. Accordingly, efficiency is expected to vary across the categories of plots: bought water plots, jointly-owned tubewell plots and single-owned tubewell water plots.

The paper assesses whether farmers in India's sugarcane belt are efficient producers of sugarcane, i.e. do they exhibit technical inefficiency? If so, how do the estimated inefficiency scores vary across plots for the three categories of water users surveyed? Furthermore, the paper attempts to explore the sources of inefficiency across farmers.

The technical efficiency hypothesis rests on two opposing factors. The first is the belief that output levels on plots where water is purchased are furthest from the production frontier, while output on plots owned by tubewell owners are closest. This arises from the fact that water owners have greater control over the resource and thus are likely to gain the highest output from inputs used due to timely irrigations that are known to affect yields (Meinzen-Dick 1995), whereas for buyers, water is a highly stochastic input. On the other hand, it is possible that efficiency in production will be highest for plots where water is purchased and lowest on plots where water is sourced from a single tubewell owner. Water purchasers typically face a higher price of water both in terms of cash price per hour as well as with respect to timing of water and reliability of its supply. Thus they use their inputs more efficiently than tubewell owners who face near zero marginal costs, due to flat rate electricity pricing, and who enjoy a more controlled access to water.

Estimation results confirm the presence of inefficiency effects amongst farmers, with water owners as the most efficient and buyers the least, thus indicating that the stochastic effects of water supply outweigh any possible water price effects. However, income gains from reducing inefficiency are highest for buyers and lowest for owners. Results from this study are pertinent for agricultural areas characterized by similar water problems, where water markets are operating under conditions of declining groundwater levels and erratic electricity supply.

THE NATURE OF GROUNDWATER MARKETS IN RURAL AREAS: A LITERATURE REVIEW

Groundwater markets typically operate as monopolistic and oligopolistic structures stemming from the large initial investments in tubewell installation and underlying hydrological features which limit the spatial distribution of water, and thus result in few water sellers. In the absence of good water transportation systems, these sellers are able to operate as monopolists. This view has been pioneered by Shah (1993), who has highlighted the benefits of markets over publicly-administered works in terms of the greater and more equitable access they give to small farmers. Due to the nature of investments arising from large fixed costs, tubewell ownership is inequitable but at the same time allows the disadvantaged poor farmer the opportunity to buy water. A shift in electricity pricing from pro-rata to flat rates would thus encourage the distribution of water amongst farmers by providing greater access from increased market activity.

Others such as Palmer-Jones (1994), Meinzen-Dick (2000) and Dubash (2002) disagree and have instead pointed to the inherent inequities present in these largely monopolistic structures and have highlighted the complexity in the nature of water contracts governed by social processes and their links with other rural markets. Palmer-Jones suggests that agricultural policies should be founded on models that consider the inequality in land ownership and other assets, asymmetries in access to information, the interlinkages of water markets with other rural markets and the "spatial nature" of water markets–all of which characterize rural conditions in developing countries. Based on evidence from Pakistan, Meinzen-Dick finds that more than half of the water buyers did not get their desired supplies. She finds water supply to be influenced by age, landholding size and technology which are expensive or infeasible to acquire. She suggests expanding tubewell ownership in the form of partnerships amongst medium sized farmers, where the social and economic disparity between water purchasers and sellers is less than that between single tubewell owners and water buyers. Dubash examines the intricate relationship between water and the institutions that evolved around it, the complex nature of contracts between water buyers and sellers and the role that society plays in shaping economic outcomes in two groundwater dependant villages in North Gujarat. He finds considerable variation in groundwater exchange in the two villages and uncovers a multiplicity of contracts governing sales -thus cautioning against generalization. He finds *uniform prices across buyers which do not differ by technology* (this is true for the village surveyed here as well; however, in spite of no difference in prices charged, effective prices do differ by tubewell technology, stemming from variation in water discharge). Dubash finds the terms of exchange to have a certain permanence to them which cannot be explained by market models but which are embedded in existing social norms and rules that guide allocation amongst farmers.

Similar issues are raised by Janakrajan (1994) who finds variations in pricing both within and between villages in Southern Tamil Nadu and highlights the inequity amongst sellers and water buyers. This inequity is enhanced by the interlinkage of water markets with markets for labor and products which are often supplied at below market prices to water suppliers. Evidence of interlinkage is also found by Jacoby, Murgai and Rehman (2004) who explore price discrimination in groundwater markets in Pakistan, where high investment costs and credit constraints influence installation of private tubewells, and conveyance losses enforce monopoly power of the seller.

This paper agrees with Shah's critics on the inherent inequities in groundwater markets but adopts a previously unexplored path of analysis and reasoning. The literature has largely focused on the political economy and the economic structure of water markets and less so on efficiency issues stemming from access to water. This paper examines the distributive equity of water markets by examining production efficiency on farmers' plots who buy water compared to those who 'own' their water, thereby questioning the equity framework[3] founded on private investment in groundwater. An examination of technical efficiency across the three categories of farmers has implications for the current supply driven policies, such as the existing groundwater laws and electricity pricing that encourage private investment in groundwater extraction. Further it examines factors causing inefficiency and integrates individual factors that influence production to explain the observed efficiency differentials. It is thus a departure from the groundwater literature reviewed as it estimates production efficiency as a whole and across different categories of water users and utilizes specific features endemic to farmers and water markets to explain their differences. [4]

THE VILLAGE SURVEY: BELAGARH[5]

Belagarh was chosen for field study as it exhibits socio-economic characteristics that are commonly found in groundwater dependant areas: fragmented landownership, informal water markets, increased private investment in tubewells, state controlled electricity supply which is erratic and heavily subsidized and a severe competition for groundwater resulting in a race to the bottom.

There are approximately 300 households in Belagarh, of which 165 are farming households with agriculture as their principal occupation. Sugarcane is widely grown in the village and is primarily for sale to the neighboring sugar mills. There exists a proper chain for sugarcane production from the time it is grown to the point where it is used by industry for distribution to consumers. Sugarcane deposit centers are present at several spots in the village from where they are transported in trucks to the neighboring sugar mills.

The official electricity schedule promises ten hours of continuous supply and follows a weekly rotation with one week of supply at night time hours followed by one week in daylight hours. However, during the summer months supply is erratic and averages six hours a day, often with frequent interruptions. During the survey round, electricity supply in the months of July and August was particularly poor and averaged five hours a day.

Groundwater is the main source of water for both domestic consumption and agriculture. Belagarh falls in the 'dark block'[6] area, typically characterized by declining levels of groundwater. When asked about the level of groundwater, farmers confirm that water has been declining and cite the rapid increase in tubewells as the cause. What remains unsaid, but is easily observable, is the fragmentation of land and the subsidized electricity - charged at a flat rate -which has provided an impetus to the growth of tubewells in the village. When asked what could be done to rectify the situation, the universal answer given was to build a canal to provide another source of irrigation while replenishing some of the groundwater. Such a canal is indeed being built, and it is the hope that this would bring the much-needed respite that farmers are seeking. True to its peculiar nature, the aquifer is a common property resource which anyone can access, whereas water is a private good and is extracted by those who own land above it. While there exist indirect regulations (which are often violated) mediated through the selective provision of loans for sinking wells or power connections for pumps, it is the inseparability of land ownership from water beneath it which allows anyone who owns land to extract unlimited amounts; that has led to the rapid depletion of groundwater. The only constraint on water is imposed by the erratic and variable electricity supply, which is particularly binding in the summer months when the crop is young. And yet, no farmer in the village will openly admit that it is the private actions of all of them that continue to undermine their livelihoods and those of their future generations. Water is sugar and sugar is income and that is what is important today.

Survey Rounds

Following a census of land-owning farming households, the village was divided into four quadrants from which a total of seventy eight tubewells – the primary sampling unit - were randomly chosen in proportion to their density in each quadrant. Of these seventy eight tubewells, more than half belong to single owners, with the remainder jointly-owned, usually between brothers. For each tubewell, we obtained information on all the plots it serviced. This totalled 326 plots owned by 105 farmers.

The first survey round was conducted in July 2004 to elicit information on irrigation details including payments for water for each plot. The survey revealed that payment terms were more or less uniform at Rs.15 per hour paid in cash. Subsequent survey rounds (in addition to the monthly irrigation survey) obtained information on labor and chemical inputs used in production, on tubewell specifics and discharge date to capture variations in the supply of water to each plot. We also tested soils for mineral content in association with the National Bureau of Soil Survey and Land Use Planning at their regional centre in Delhi. From January to April 2005, we obtained harvest data for all plots. The final round in May 2005 comprised the household roster round and obtained basic demographic and household data. Select summary statistics are presented at the end of this paper.

Tubewells

There were two types of plots serviced by the seventy-eight tubewells: those belonging to the owner (single or joint) and those to which water was sold. The 78 tubewells surveyed were of two kinds: submersible (32) and non-submersible (46), with the former being deeper than the latter. With respect to ownership, 49 were under a single owner while 29 were jointly-owned. Within the jointly-owned tubewells, a partnership of four was most popular followed by a partnership of three. One tubewell in the survey had a partnership between 10 people.

Water markets (defined as the sale of surplus water to other farmers) are more prevalent under single ownership of tubewells than under jointly-owned tubewells. This is expected, as water sold is surplus to the needs of the owner farmers. In the case of jointly-owned tubewells, water must be routed to all partners' lands and then the surplus sold. With an erratic supply of electricity, it is not surprising that the sale of water is more frequent in the case of single ownership where only one farmer's land must be irrigated versus several for jointly-owned plots, which usually followed a rotational pattern. Although average area served per plot is much lower for jointly-owned water plots than single-owned ones, the number of plots served is greater for the former than the latter. Thus, a glitch in the water distribution cycle due to erratic electricity supply delays the routing process to buyers' plots, and those at the end of the rotational cycle for jointly served plots are the last to receive water.

Irrigation and Labor

Of the 326 plots, 38 percent received water from jointly-owned sources, 35 percent from single-owned water sources and 27 percent bought water. Average area served was the largest for single-owned water sources with the smallest being for bought water plots. This is expected, as farmers with larger plots of land derive the greatest benefit from tubewells through secure and controlled access to water.

A binary measure of flooded irrigation (i.e. a yes or no response to having received flooded[7] irrigation) summed across the first seven irrigations is taken as the first indicator of good water flow.[8] Of the single-owned tubewell plots, 96 percent reported having flooded irrigation for the first seven irrigations. The corresponding numbers for joint tubewell plots and purchased water plots is 86 percent and 75 percent.

A maximum of fifteen irrigations was recorded over the entire sugarcane cropping season, with only six plots receiving all fifteen. Of these six plots, four received water from single-owned and two from jointly-owned tubewell sources. Only two buyers' plots received a maximum of thirteen irrigations. Further, only 36 percent of bought water plots completed five irrigations prior to the monsoon season, whereas 73 percent of single-owned tubewell achieved the same.

The mean depth of irrigation, recorded in inches, favours single-owned tubewell water plots consistently over all irrigations. Timing of water supply is crucial for sugarcane growth in the driest months when it is most vulnerable. Using average gap between irrigations as a variable for timing, the data suggest that single-owned tubewell water plots were more regularly and frequently irrigated (and closely followed by jointly-owned tubewell water plots) than buyers' plots. Erratic electricity supply, which was particularly high and infrequent in the summer months of June and July, discriminates against buyers as water is only distributed in surplus to the needs of the seller, thus contributing to the lag between successive irrigations. Using mean depth, average gap in irrigation days, and the timing of irrigations as proxy indicators for the volume of water, we find that water application for single-owned tubewell water plots is higher than those for purchased water plots. Hence, farmers buying water are disadvantaged on all three counts.

Labor inputs are used at various stages in the sugarcane cycle and for different activities. Disaggregating labor by plot type, it is observed that labor is most intensely used on purchased water plots. Substitution of labor effort for irrigation on these plots cannot be ruled out, as labor can be used more intensively to make the most of water.

Harvest and Yields

Sugarcane is an annual crop, and has a three-year life span. Yields increase over this period after which they are replaced by the fresh sown crop. The sugarcane harvest begins at the end of October/early November and continues until the end of March/early April. Harvesting is a continuous rather than a discrete process and is conditioned by the demand for sugarcane from the neighboring sugar mills.

Survey data show that for single-owned tubewell plots yields were 58 quintals per bigha, 58.6 on jointly-owned plots, and 53.2 quintals per bigha on bought water plots. As expected, yields on bought water plots are lower than for jointly owned water and single owner tubewell plots with the difference for the last two being very small.

ECONOMIC EFFICIENCY AND THE FRONTIER

Economic efficiency is described by its component parts: technical efficiency and allocative efficiency (also known as price efficiency). A farmer is more technically efficient (TE) than his/her counterpart if he/she produces a higher output from a similar bundle of inputs. Allocative efficiency (AE) is reached when the marginal cost of input is equal to the value of the marginal product of output. The concept of economic efficiency is intimately linked with Farell's (1957) work, and has been subsequently applied by Aigner and Chu (1968), Aigner, Lovell and Schmidt (1977), Meeusen and van der Broeck (1977), Kumbhakar and Lovell (2000) and Reinhard et al (2002).

Methodology: Parametric Production Frontiers

The neoclassical production function[9] (Kalirajan and Shand, 1999) for a firm (or farmer) producing a single output and using multiple inputs following best practices is shown by:

$$Y^*_i = f(x_{i1,} x_{i2} \ldots x_{im}, ß) \tag{1}$$

where Y^*_i and X_i are output and inputs at the frontier of the *i*th firm, *ß,* is the parameter to be estimated and *f(.)* is the production frontier. In the neoclassical framework, it is assumed that the firm operates at the optimum level of technical efficiency. Thus, any inefficiency that arises is attributable to allocative inefficiency. In practice, firms do not operate at the optimum due to economic constraints, information gaps and non-price factors, all of which prevent them from utilizing their inputs optimally. Slackness in production is thus introduced by modifying the neoclassical production function to include technical inefficiency:

$$Y_i = f(x_{i1,} x_{i2} \ldots x_{im}, ß)\ TE_i \tag{2}$$

where TE_i represents technical inefficiency of the *i*th firm. Thus TE_i is specific to each producer and represents the shortfall in production. The values ascribed to TE_i depend on whether the firm faces any other non-market constraints. If it does not then TE_i is one, and there is no inefficiency, otherwise it is < 1. In the description above, TE_i is an output-oriented measure of technical inefficiency and can be defined by:

$$TE_i = \textit{Observed Output / Maximum attainable output} =$$
$$Y_i / Y^*_i = Y_i / f(x_{i1,} x_{i2} \ldots x_{im}, ß) \tag{3}$$

where $f(x_{i1,} x_{i2} \ldots x_{im}, ß)$ represents output at the frontier. In the expression above, only values of output captured in the numerator are observed, while the denominator is not observed. There are various ways to measure TE_i and thereby the denominator representing best practices. Parametric methods employ deterministic and stochastic models. The deterministic models assume that all endogenous factors affecting production are under the control of the decision-making unit. Hence, the gap observed between the frontier and observed output levels is attributable to technical inefficiency, captured by TE_i. However, there are some exogenous factors that affect production, which are not in the control of the production unit, such as weather, information gaps and erratic electricity supply, and which must be distinguished from those that can be controlled. In addition, errors due to model misspecification are also included under technical inefficiency in deterministic parametric methods. Stochastic methods, on the other hand, allow for specification anomalies, exogenous shocks and other uncontrollable factors independent of technical efficiency, by decomposing the error term into random noise v_i and pure technical inefficiency u_i. The stochastic model employed in this paper is illustrated by the following specification

$$Y_i = f(X_i ;\beta)\, exp(\varepsilon_i = v_i - u_i) \qquad with\ u_i \geq 0; \tag{4}$$

where Y_i represents output on the *i*th plot; X_i are the input variables associated with the *i*th plot; , is a vector of unknown parameters to be estimated; v_i is a symmetric error term that represents statistical noise and is *iid* (identical and independently distributed), u_i represents the asymmetric and one-sided non-negative random variable associated with technical inefficiency. The term u_i is *iid* and is obtained as truncations at zero of the normal distribution[10]. Both v_i and u_i are independently distributed of each other. Using equation 3 and 4, TE_i is defined as

$$TE_i = Y_i \,/\, f(X_i ;\beta)\, exp(v_i) \tag{5}$$

$$= f(X_i ;\beta)\, exp(\varepsilon_i = v_i - u_i) \,/\, f(X_i ;\beta)\, exp(v_i) = exp(-u_i) \tag{6}$$

where $f(X_i ;\beta)\, exp(v_i)$ is the stochastic frontier output or Y* in equation 3 and $v_i \sim N(0, \sigma_v^2)$; and $u_i \sim |\, N(0, \sigma_u^2)$ with u_i being distributed as half normal.[11]

Variations in efficiency estimates at the plot level can arise due to a number of farmer-specific characteristics, such as education and age of the farmer, experience in crop cultivation, distance of the plot from the water source, discharge rate of the tubewell and area of land cultivated. In the surveyed village, variations in output are thus modelled as a function of these farmer specific characteristics

$$u_i = Z_i\, \delta + W_i \tag{7}$$

where Z_i is a vector of explanatory variables associated with technical inefficiency and δ is the corresponding vector of parameters to be estimated. W_i is a random error term and is defined by the truncation of u_i such that $W_i \geq - Z_i \delta$ which preserves the condition of $u_i \geq 0$.

To incorporate the determinants of technical efficiency, *TE* scores are regressed on the chosen explanatory variables that are likely to influence efficiency in a single step (Battesse and Coelli, 1995). This simultaneously estimates the parameters of the production function and those of the efficiency determinants by making use of the error term described as a function of the Z_i variables in equation (7). The model used in this paper is a variant to the Huang and Liu[12] model as the variable 'area' is included both in the stochastic production model and as a determinant of inefficiency. A similar approach has been applied by Battese and Coelli (1995), Battese and Broca (1997) and Madau (2005). Battese and Coelli (1995) explain that inclusion of a variable in both the stochastic frontier and the inefficiency effects is possible when the inefficiency effects are stochastic. We test for that and find that they are indeed stochastic. In the model used, area influences both the structure of production - where it measures the response of output to cultivated area, and the error component - where it captures inefficiency by plot size. Inclusion in the latter is motivated by farmers primarily being driven by size of their plots to invest in tubewell technology.

Technical efficiency is thus obtained from equation (6) and equation (7)

$$TE_i = exp(-u_i) = exp\ (- Z_i \delta - W_i) \mid \varepsilon_i \tag{8}$$

Since u_i is non negative, TE scores are bounded between 0 and 1 as $0 \leq \exp(-u_i) \leq 1$. Using maximum likelihood estimation methods, technical efficiency is estimated for each observation or plot. In addition, the coefficient vector β for the X_i inputs, and parameter estimates, δ, of the Z_i covariates, and the variance parameters σ^2 and λ defined as[13]

$$\sigma^2 = \sigma_u^2 + \sigma_v^2 \tag{9}$$

$$\lambda = \frac{\sigma_u}{\sigma_v} \tag{10}$$

are also estimated. Using the Battese and Corra (1977) reparametrisation,

γ is instead defined in equation (11), and lies between 0 and 1. This can be searched to find a suitable starting value for an iterative maximisation process.

$$\gamma = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2} \qquad (11)$$

where $0 < \gamma < 1$. To obtain parameter estimates, a functional form must be specified. The Cobb Douglas production form is chosen over the Translog after testing for its suitability. Summary statistics of the variables used in the estimation of the stochastic production function are presented in Table 1.

RESULTS AND DISCUSSION

Hypothesis tests were conducted hypothesis tests on the suitability and validity of the efficiency model by employing the log likelihood ratio test where the suitability of the restricted model (H_0) was tested against the unrestricted model (H_1) (Wooldridge 2000). The test is defined by:

$$\lambda = -2\left[\ln \frac{L(H_o)}{L(H_1)}\right] = -2\left[LnL(H_o) - LnL(H_1)\right] \qquad (12)$$

where Ln(H_0) is the log likelihood value obtained from running the restricted model and Ln(H_1) is the log likelihood value obtained from running the unrestricted model. Using the likelihood ratio, five tests were performed to test the suitability of the frontier model incorporating inefficiency effects using Coelli's frontier computer package FRONTIER 4.1 (Coelli 1996). These were on the inefficiency effects being stochastic, on the suitability of the stochastic frontier model versus a deterministic model, the absence of technical inefficiency effects, no farmer specific effects and the joint significance of inefficiency determinants. These tests affirm the use of the stochastic production function, the presence of inefficiency, and the joint influence of farmer specific effects on technical inefficiency. Furthermore, a series of model selection tests were conducted to select the appropriate variables for inclusion in the Cobb Douglas production function.[14] Coefficient estimates of the stochastic frontier models are presented for frontier and inefficiency analysis (Tables 2a, 2b and 3) and are a variant of Model

A with variations arising in the irrigation term and interaction between input variables and water type associated with each plot:

Model A: $Y_i = f(X_i : \beta) + \varepsilon$ where X= area, labor, manure, fertilizer, tractors, oxen, irrigation, interact (crop dummy*labor) and sandyloamy (soil dummy)

Production Estimates

The parameter estimates for Model A and Model B indicate that with the exception of fertilizer all the input variables indicate a positive relationship with output. Manure is not significant and field observations show that manure was applied largely as a residual input. An explanation for the low but significant negative elasticity of fertilizer costs is derived from the delay in the monsoon rains. This affected not only the timing and frequency of waterings due to poor and erratic power supply, but also the interaction of water, a highly stochastic input, with a predetermined input such as fertilizer, leading to a reduced impact of expenditures on output. The insignificant estimate of irrigation post-31 July stems from a tapering off of irrigations with the arrival of the monsoons. The summer months coincide with the growing period for sugarcane and are crucial to plant growth, which explains the significant and positive relationship for irrigation pre-31 July. The negative elasticity on the interaction of labor with crop dummy indicates that labor for fresh-sown sugarcane reduces output by 7 percent for every hourly increase in labor. This result has been found in other studies, such as rice farmers in India and Bangladesh (Fuwa et al. 2005; Sharif and Dar 1996) and wheat farmers in Pakistan (Battese and Broca 1997). Data gathered revealed that farmers used labor more for the fresh sown crop, as opposed to the pre-existing crops, and tended to overcompensate by applying more labor.

The model selection test reveals a difference in slopes for select input variables: land area and tractors–both strong correlates of wealth–and irrigation; all three arise from differential access to water. Sugar cane cultivation is a labor intensive activity. The use of tractors is limited to land preparation, weeding and digging. In the survey year, the delayed arrival of the rains could have resulted in farmers (for plots with singly-owned and jointly-owned tubewells) to use the tractors more extensively when output is lower, thus acting as an "inverse" indicator for rainfall and poor irrigation conditions (Battese and Coelli, 1995, found similar results for bullock labor). Further, the data revealed that tractors and oxen were in fact substitutes, which can explain their limited role on singly-owned and jointly-owned plots.

The negative elasticity of irrigation before 31 July[15] for single and joint tubewell owners' plots may appear counterintuitive, but given that irrigation was highly dependant on electricity supply, it is not surprising that tubewell owners tended to over-irrigate their fields. Field observations indicate that farmers' control was heavily constrained by (unpredictable) electricity shortages. This led to a "run on the pumps" with farmers operating their tubewells for several days during intermittent supply until their fields were fully flooded.

Technical Efficiency

Technical efficiency is defined as the maximum possible increase in output with the same bundles of inputs. Thus, technical efficiency can be viewed as redistribution of the current resources to increase production to its maximum. Technical efficiency estimates show that the average output-oriented efficiency score across all models for all farmers is 0.85, which implies that on average the output produced is 85 percent of the frontier output. An average TE score of 0.85 implies that output on all plots taken together for all three categories of water users can be increased by 15 percent through a more effective use of the input bundle given the present state of technology.

The structure of production is captured by variable γ and the parameter estimates of the Z_i covariates (Tables 2a and 2b). The variance parameter γ is significant in all models, thus technical efficiency is significant in explaining output variability amongst surveyed farmers.[16] An alternate measure of the structure of production is provided by γ^* (Coelli T.J.1995; Coelli et al. 1998; Kumbhakar and Lovell 2000) which reveals that a little more than half of the differential between observed and best practice output arises from the existing difference in efficiency across farmers.

Efficiency scores for the three types of water users in Table 3 indicate that buyers' plots always record lower than average TE scores whereas single owners' plots record higher than average TE scores. Further, buyers' plots always have the lowest score amongst the three types of farmers, ranging from 0.79 to 0.81, indicating the greatest potential for increase in output from a more effective use of their input bundles. On the other hand, for single owners' plots the range was between 0.88 and 0.89 and for joint owners plots it was between 0.84 and 0.85. A test of means was conducted across plots by user type to assess whether the difference in TE scores was significant. The test results indicate that the estimated TE scores were significantly different amongst the three types of water users, and thus attributable to the input mix adopted by the three types of farmers.

Thus, these TE scores reveal that on average, owner plots could increase output by 11 percent, joint owner plots by 15 percent and buyer plots by 20 percent. In terms of income gains, such potential increases in output across the three categories translate to Rs.649 per bigha for owners' plots, Rs. 889 for joint owners' plots, and Rs. 1082 per bigha for buyers' plots. Thus income gains follow an inverse relationship to access to water with income gains increasing with improved control over water. For all farmers' plots as a whole, income gains averaged Rs. 867 ($1=Rs.44) per bigha.

With respect to the determinants of inefficiency, Tables 2a and 2b show that all five variables when taken together are significant in explaining inefficiency even though individually some may not be. A negative sign on the variables implies an increase in technical efficiency whereas a positive sign shows the reverse. Farmers' education and area of land cultivated show a positive effect on efficiency whereas weak negative effects are shown by distance of a tubewell from the plot that it irrigates and by discharge, the latter possibly arising from wastage and standing water in the fields. Hence, returns to education are positive while an increase in land area suggests scale economies. Inefficiency from an increased distance between water source and plots is explained by the greater time taken for water to reach the plot and ensuing seepage losses from the unlined channels prevalent in the village. However the effect is weak as most irrigated plots were contiguous to each other.

CONCLUSIONS AND POLICY IMPLICATIONS

This paper uses the stochastic frontier production function to estimate technical efficiency amongst a cross section of sugarcane growing farms in North India and allows us to reach a number of conclusions. (1) The results of the study indicate the presence of technical inefficiency, which captures between 51 to 55 percent of the differential between current and best practice output. (2) This inefficiency implies that farmers can improve sugarcane output by redistributing their current input bundle. Further, (3) the study reveals that plots serviced by owner's tubewells had the highest efficiency scores followed by plots serviced by jointly held tubewells. Water buyer's plots ranked the lowest. Estimates from the disaggregation of the production function by water user type (Model A1 and Model B1) indicate that amongst the three categories of water users, (4) water is poorly used on single- and joint-owner tubewell plots to overcompensate for the periodic lack of water. (5) This misallocation is brought about by the uncertainty in the electricity schedule, since electricity is the source of power for pumpsets that run the tubewells. Consequently, farmers with their own tubewells (single and joint categories) are almost always running their tubewells in the summer to ensure against future uncertainties. (6) With respect to potential income gains from improved efficiency, the largest gains would accrue to the most water-rationed plots, followed by joint water plots, suggesting that water ownership disproportionately favors owners and is highly inequitable. This occurs despite the suboptimal use of inputs on plots serviced by their own tubewells.

In the surveyed village, as in the rest of the sugarcane growing belt, the lack of reliable alternative sources of irrigation (including from canals and publicly-provided tubewell water) has driven the farmers to invest in tubewells to insure against uncertainties in the monsoon showers. Further, the growth of lucrative crops such as water-thirsty sugarcane also demands timely application of inputs that are to a large extent conditioned by the availability of water at the appropriate times. Tubewell technology requires large initial investments. With declining water tables, tubewell installation costs have been steadily increasing. Despite these rising costs, farmers have been increasingly investing in their own tubewells, indicating an unrelenting demand for water.

The only bottleneck to sugarcane production arises from the availability of water conditioned largely by electricity: the supply of other inputs is not rationed. Because water is the constrained resource, we can conclude that a package of policy interventions is needed that will improve the technical and institutional environment around water use. Farmers differ in their access to water due to large upfront costs for tubewell installation which then gets exacerbated by the erratic supply of water to its users (be it buyers or joint partners in ownership) further down the supply chain. Hence, removing inequities in access to water can alleviate some of the current inequities in production and income across farmers. Bottlenecks in water availability can be smoothened by ensuring a regular power supply, which would remove the uncertainty in water availability (and hence reduce the indiscriminate use of water by owners) and ensure timely supplies to all water user types. Thus a reliable power supply would improve the economic well-being of farmers, especially buyers who tend to be smaller and resource poor.

The farmers' response to their particular situation is to acquire greater control over water and thereby to the production process to augment yields, and to reduce their dependency either on the state or water sellers. Technical efficiency estimates across the three types of plots show that water markets operating in an electricity constrained (and hence water constrained) environment disproportionately favor plots of tubewell owners over those of water buyers, but this to a certain extent is undermined by the spatial distribution of plots. Therefore a shift towards joint ownership of tubewells should be encouraged to reduce the disparity between water buyers' and water owners' plots and to achieve a more equitable distribution of water and efficient production. This can be achieved by preferential loans, technical assistance and by fostering institutions that support collective action (Meinzen-Dick 2000). Tubewell partnership also addresses the high initial capital costs of investment and continuing fragmentation of land. The functioning of water markets reveals that misallocation of water on plots serviced by tubewells can be overcome by providing a regular supply of power. The operating environment in the village reveals that peer pressure exercised by a tacit village-level understanding of water sharing amongst farmers acts as a proxy for an institutional force that seeks to regulate the distribution of water. Thus village-level institutions composed of farmers' groups should be encouraged to regulate the functioning of water markets thereby reducing the monopoly power of water owners.

Sources of inefficiency show that the education of the farmer is imperative in reducing technical inefficiency. Hence, training should be provided to farmers on best practice techniques that include the application of inputs common in the production process. Although a weak effect, a larger distance of plots from tubewells works against efficiency. Alternative and cheaper modes of transportation such as flexible plastic pipes could be explored to mitigate inefficiency effects.

The determinants of inefficiency also reveal that land fragmentation reduces efficiency as water must be transported over long distances. However, while land fragmentation reduces efficiency, it also favours a more egalitarian distribution than had land consolidation taken place. In the surveyed village, the scattering of plots meant that tubewell owners confined their tubewell investments to their relatively larger plots and were buyers for their smaller plots. Hence, a water seller was also a water buyer on his smaller plot. The dual role of farmers was also reinforced by the lack of water transportation systems limiting tubewells to service only the neighboring plots. Additionally the operation of a centrally-determined village-level price implied a 'moral' economy where sellers could not unilaterally change the water tariffs without being blacklisted, and most importantly could not ignore the repercussions on themselves on plots where they were buyers. Thus the spatial spread of plots, buttressed by social norms, mitigates against the operation of monopoly powers.

Farmers will continue to invest in tubewells rather than to rely on water markets in an environment where inequities in output and in water supply exist between water user types. Water exchanges in an environment where farmers feel obliged to supply water (motivated either by a tacit moral economy or profit) ameliorates to a certain extent the disparity in a water-constrained world, but does not stop the draw down of the water table. Conditions of uncertainty have deleterious effects on efficiency in production where farmers adopt a sub-optimal mix of inputs conditioned by the vagaries in water availability. Therefore a policy package combining a regular supply of electricity supply, joint ownership of tubewells, support for farmer-led village institutions to monitor the functioning of water markets, technical training of farmers and alternate modes of water transportation will constitute important steps toward improved agricultural efficiency and equity amongst cultivators.

NOTES

* I would like to thank Prof. J Cuddy, Prof. H Genberg, Dr. F Madau, Prof. N Khanna, Prof. S Kumar, W. Reidhead and D. Eggel for their suggestions. I am grateful to Prof. A Banerji and Prof. J.V. Meenakshi for making fieldwork in India possible and to Ajay Kumar and Rajpal Singh for field assistance. Thanks to Ch. Ranjit Singh's family for hospitality in Belagarh village. Partial funding from the Department of Economics, IUHEI, for author's fieldwork participation is gratefully acknowledged. Fieldwork was financed by a grant from the South Asian Network for Development and Environmental Economics (SANDEE).

[1] One bigha equals one fifth of an acre

[2] India is the second largest producer of sugarcane next to Brazil (in 2001), and Uttar Pradesh has the highest production. Some quick calculations show that gross returns are the highest for sugarcane (Rs.4033 per bigha) than for other commonly grown crops such as wheat (Rs. 1333 per bigha) and Rice (Rs. 821per bigha), thus explaining why farmers find sugarcane lucrative (Agricultural Statistics at a Glance 2004, Government of India, www.agricoop.nic.in).

[3] Shah's (1993) understanding of groundwater markets has been instrumental in influencing the flat rate electricity tariffs adopted by several state governments (Palmer-Jones 1994).

[4] A notable exception is the work of Vaidyanathan and Sivasubramaniyan (2004) who calculate water use efficiency using other techniques for different crops and in different agro-climatic regions of India at the basin level and between irrigated and rainfed areas. However they do not disaggregate by type of water user.

[5] The true identity of the village has been hidden and the name changed.

[6] Dark Block is defined as the stage of groundwater development where use exceeds 85 percent of annual replenishable recharge. Other categories are 'grey blocks' and 'white blocks defined by water usage between 65-85 percent of annual recharge and less than 65 percent of annual recharge respectively (Government of India, www.india.gov.in).

[7] Flooded irrigation refers to several inches of standing water that slowly soaks through the soil; this is very inefficient and much water is lost through evaporation.

[8] The first seven irrigations were used as most plots recorded having irrigated their plots. After seven irrigations, the frequency of irrigated plots started decreasing.

[9] A production function shows the relationship between outputs and the inputs used to produce it. It is stochastic when the residual error term is split into a purely random shock and those variables that are within the control of the producing agent.

[10] Ui is allowed to vary from 0 to positive values unlike a normal distribution where you have values on both sides of zero or the mean, that is + and – of zero. Here the error term is one sided as u relates to inefficiency and is by assumption truncated.

[11] See Fuwa, Edmonds and Banik (2005) and Kumbhakar and Lovell (2000) on distributional assumptions.

[12] Huang and Liu's (1994) model is characterized by a TE effects model where some of the z variables are interacted with the x input variables included in the stochastic production function (Kumbhakar and Lovell 2000).

[13] Of the associated log likelihood function expressed using sample variance parameters.

[14] Test results are available on request from the author.

[15] Negative elasticities in frontier models indicate that input use of the respective variable should not be associated with best practice production (Battese and Broca 1997).

[16] A value of $\gamma = 1$ indicates that all deviations from the best practices frontier are due to technical inefficiency whereas a value of 0 indicates white noise.

REFERENCES

Aigner, D.J. and S.F. Chu. 1968. On estimating the Industry Production Function. *The American Economic Review*, Vol. 58, 4, 826-839.

Aigner D. J., C.A.K Lovell and P Schmidt. 1977. Formulation and Estimation of Stochastic Production Function Models. *Journal of Econometrics*, 21-38.

Battese, G. E and G. S. Corra. 1977. Estimation of a Production Frontier Model: With Application to the Pastoral Zone of Eastern Australia. *Australian Journal of Agricultural Economics*, Vol. 21, 3, 169-179.

Battese, G.E and T J Coelli. 1995. A Model for Technical Inefficiency Effects in a Stochastic Frontier Production Function for Panel Data. *Empirical Economics*, Vol. 20, 325-332.

Battese, G. E and S. S. Broca. 1997. Functional forms of stochastic frontier production functions and models for technical inefficiency effects: a comparative study for wheat farmers in Pakistan. *Journal of Productivity Analysis* Vol 8: 395-414.

Coelli, T. J. 1995. Estimators and Hypothesis Tests for a Stochastic Frontier Function: A Monte Carlo Analysis. *Journal of Productivity Analysis*, Vol. 6, 247-268.

Coelli, T. J 1996. *A Guide to Frontier Version 4.1: A Computer Programme for Stochastic Frontier Production and Cost Function Estimates.* University of New England, Armidale, NSW, Australia.

Coelli, T, D.S. P. Rao and G. E. Battese. 1998. *An Introduction to Efficiency and Productivity Analysis*. Kluwer Academic Publishers, Boston.

Dubash, N. 2002. *Tubewell Capitalism: Groundwater Development and Agrarian Change in Gujarat.* Oxford University Press, New Delhi, India.

Farell, M.J. 1957. The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society.* Vol. 120.

Fuwa, N., C. Edmonds and P. Banik. 2005. How Inefficient are Small-Scale Rice Farmers in eastern India Really? Examining the Effects of Microtopography in Technical Efficiency Estimates. *East-West Center Working Paper* No. 79., Honolulu.

Government of India. 2002. *National Water Policy*.

Jacoby, H. G., R. Murgai and S. Ur Rehman. 2004. Monopoly Power and Distribution in Fragmented Markets: The Case of Groundwater. *The Review of Economic Studies*, Vol. 71, 783-808.

Janakarajan, S. 1994. Trading in Groundwater: A Source of Power and Accumulation in *Selling Water: Conceptual and Policy Debates over Groundwater Markets in India.* VIKSAT, Ahmedabad, India.

Kalirajan, K. P. and R. T. Shand. 1999. Frontier Production Functions and Technical Efficiency Measures. *Journal of Economic Surveys*, Vol. 13, 2, 149-172.

Kumbhakar, S. C. and C.A.K. Lovell. 2000. *Stochastic Frontier Analysis*. Cambridge University Press, United Kingdom.

Le Moigne. G, S. Barghouti and L. Garbus. 1992. Developing and Improving Irrigation and Drainage Systems. *World Bank Technical Paper*, No. 178.

Madau, F. A. 2005. Technical Efficiency in Organic Farming: An Application on Italian Cereal Farms Using a Parametric Approach. *Presented at the X1th Congress of the EAAE*, Copenhagen, Denmark, August 24 –27, 2005.

Meeusen. W and J. van Den Broeck. 1977. Efficiency Estimation from Cobb Douglas Production Functions with Composed Error. *International Economic Review*, Vol. 18, 2, 435-444.

Meinzen-Dick, R. 1995. Timeliness of Irrigation: Performance Indicators and Impact on Agricultural Production in the Sone Irrigation System, Bihar. *Irrigation and Drainage Systems*, Vol. 2, 371-387.

Meinzen-Dick, R. 2000. Public, Private and Shared Water: Groundwater Markets and Access in Pakistan in *Negotiating Water Rights* (ed) Bryan Randolph Bruns and Ruth Meinzen-Dick. Intermediate Technology Publications, United Kingdom.

Palmer-Jones, R. 1994. Groundwater Markets in South Asia: A Discussion of Theory and Evidence in *Selling Water: Conceptual and Policy Debates over Groundwater Markets in India.* VIKSAT, Ahmedabad, India.

Reinhard, S., C.A.K. Lovell and G. Thijssen. 2002. Analysis of Environmental Efficiency Variation. *American Journal of Agricultural Economics*, Vol. 84, 4, 1054-1065.

Shah, T. 1993. *Groundwater Markets and Irrigation Development: Political Economy and Practical Policy.* Oxford University Press.

Sharif, N. R. and A. A. Dar. 1996. An Empirical Study of the Patterns and Sources of Technical Inefficiency in Traditional and HYV Rice Cultivation in Bangladesh. *Journal of Development Studies* 32, 612-629.

Vaidyanathan A and K Sivasubramaniyan. 2004. Efficiency of Water Use in Agriculture. *Economic and Political Weekly,* July 3, 2989-2996.

Wooldridge, J. M. 2000. *Introductory Economics: A Modern Approach*. South Western College Publishing.

Table 1: Summary Statistics of Variables Used in the Analysis

Variables	Mean	Std. Dev.
output (in quintals)	443.22	430.16
area (in bighas)	7.49	6.21
labor (in hours)	1302.23	1189.12
manure (in quintals)	116.19	228.42
fertilizer (value in Rupees)	1704.15	1686.36
tractor (in hours)	7.91	22.15
oxen (in hours)	86.37	99.62
irrigationbefore1july (bigha-inch*)	105.69	107.32
irriafterr31july (bigha-inch)	116.83	113.25
Interact (labor*crop dummy, where crop dummy=1 if fresh sown sugarcane, 0 for pre-existing sugarcane)	492.36	708.36
sandyloamy (soil dummy= if soil is sandy loamy, 0 otherwise)	.72	.45
Determinants of inefficiency		
edu (education of farmer in years)	8.61	4.55
area (in bighas)	7.49	6.21
age (of farmer in years)	45.71	12.13
distance (of plot from water source (in meters))	107.09	134.83
discharge (of tubewell in litres/sec)	14.57	4.85

N = 326

**This is a volumetric measure where area of land measured in bighas was multiplied by height of standing water.*

Table 2a: Estimates of the stochastic production function and inefficiency effects model for irrigation as a single variable and by types of water users

MODEL A:			**MODEL A1 :**		
Variable	**Estimate**	**S.E**	**Variable**	**Estimate**	**S.E**
β_0 Constant	3.892	(0.177)*	β_0 Constant	3.412	(0.218)*
β_1 Area	0.738	(0.421)*	β_1 Area	0.632	(0.064)*
β_2 Labor	0.0631	(0.027)*	β_2 Area*Singleowner	0.215	(0.099)*
β_3 Manure	0.005	(0.006)	β_3 Area*Jointowner	0.129	(0.068)*
β_4 Fertilizer	-0.032	(0.017)*	β_4 Labor	0.066	(0.025)*
β_5 Tractor	0.097	(0.019)*	β_5 Manure	0.004	(0.006)
β_6 Ox	0.100	(0.016)*	β_6 Fertilizer	-0.035	(0.017)*
β_7 Irrigation	0.059	(0.024)*	β_7 Tractor	0.133	(0.029)*
β_8 Interact	-0.076	(0.007)*	β_8 Tractor*Singleowner	-0.026	(0.025)
β_9 Sandyloamy	-0.015	(0.023)	β_9 Tractor*Jointowner	-0.070	(0.030)*
δ_0 Constant	0.393	(0.238)*	β_{10} Ox	0.106	(0.154)*
δ_1 Education	-0.028	(0.009)*	β_{11} Irrigation	0.185	(0.048)*
δ_2 Age	-0.003	(0.003)	β_{12} Irrigation**Singleowner*	-0.265	(0.088)*
δ_3 Area	-0.043	(0.019)*	β_{13} Irrigation*Jointowner	-0.135	(0.054)*
δ_4 Distance	0.003	(0.0002)**	β_{14} Singleowner	0.990	(0.308)*
δ_5 Discharge	0.009	(0.006)**	β_{15} Jointowner	0.498	(0.190)*
			β_{16} Interact	-0.075	(006)*
			β_{17} Sandyloamy	-0.008	(0.024)
			δ_0 Constant	0.406	(0.217)*
			δ_1 Education	-0.020	(0.009)*
			δ_2 Age	-0.003	(0.003)
			δ_3 Area	-0.041	(0.0178)*
			δ_4 Distance	0.0002	(0.0002)
			δ_5 Discharge	0.008	(0.006)**
σ^2	0.073	(0.013)*	σ^2	0.067	(0.013)*
γ	0.752	(0.069)*	γ	0.743	(0.073)*
$\gamma^* = \gamma / \left[\gamma + (1-\gamma)\frac{\pi}{\pi - 2}\right]$ = 0.52			$\gamma^* = \gamma / \left[\gamma + (1-\gamma)\frac{\pi}{\pi - 2}\right]$ = 0.51		
log likelihood function = 85.19			log likelihood function =93.63		

Figures in brackets are standard error

Table 2b: Estimates of the stochastic production function and inefficiency effects model for pre-and post31july irrigation and by types of water users

MODEL B:			**MODEL B1:**		
Variable	**Estimate**	**S.E**	**Variable**	**Estimate**	**S.E**
β_0 Constant	3.866	(0.164)*	β_0 Constant	3.523	(0.186)*
β_1 Area	0.740	(0.041)*	β_1 Area	0.657	(0.060)*
β_2 Labor	0.062	(0.026)*	β_2 Area*Singleowner	0.103	(0.073)**
β_3 Manure	0.006	(0.006)	β_3 Area*Jointowner	0.100	(0.066)**
β_4 Fertilizer	-0.032	(0.017)*	β_4 Labor	0.071	(0.025)*
β_5 Tractor	0.100	(0.018)*	β_5 Manure	0.003	(0.006)
β_6 Ox	0.103	(0.015)*	β_6 Fertilizer	-0.030	(0.017)*
β_7 Irrigation <31July	0.076	(0.026)*	β_7 Tractor	0.139	(0.029)*
β_8 Irrigation <31July	-0.007	(0.017)	β_8 Tractor* Singleowner	-0.040	(0.026)**
β_9 Interact	-0.074	(0.007)*	β_9 Tractor* Jointowner	-0.081	(0.030)*
β_{10} Sandyloamy	-0.015	(0.023)	β_{10} Ox	0.100	(0.015)*
δ_0 Constant	0.253	(0.183)**	β_{11} Irrigation <31July	0.167	(0.039)*
δ_1 Education	-0.029	(0.011)*	β_{12} Irrigation <31July*Singleowner	-0.154	(0.061)*
δ_2 Age	-0.002	(0.003)	β_{13} Irrigation <31July*Jointowner	-0.117	(0.049)*
δ_3 Area	-0.043	(0.012)*	β_{14} Irrigation>31July	-0.007	(0.018)
δ_4 Distance	0.005	(0.0002)*	β_{15} Singleowner	0.535	(0.186)*
δ_5 Discharge	0.009	(0.006)**	β_{16} Jointowner	0.385	(0.142)*
			β_{17} Interact	-0.071	(0.007)*
			β_{18} Sandyloamy	-0.009	(0.023)
			δ_0 Constant	0.337	(0.222)**
			δ_1 Education	-0.019	(0.009)*
			δ_2 Age	-0.003	(0.003)
			δ_3 Area	-0.043	(0.017)*
			δ_4 Distance	0.0002	(0.0002)**
			δ_5 Discharge	0.009	(0.006)**
σ^2	0.083	(0.019)*	σ^2	0.071	(0.014)*
γ	0.773	(0.070)*	γ	0.768	(0.063)*

$\gamma^* = \gamma / \left[\gamma + (1-\gamma)\frac{\pi}{\pi - 2}\right] = 0.55$ $\gamma^* = \gamma / \left[\gamma + (1-\gamma)\frac{\pi}{\pi - 2}\right] = 0.53$

log likelihood function = 87.68 log likelihood function = 94.73

Figures in brackets are standard errors

Table 3: Technical efficiency across farmers

Model A	All	Single owners*	Joint owners*	Buyers*
Mean TE	.848	.888	.846	.798
S.D	.101	.077	.087	.122
Min	.395	.451	.529	.395
Max	.980	.980	.967	.954
Observation	326	115	123	88

Difference between means *(t-test): *Owners and Joint: t =3.9465; P > |t| = 0.0001*
**Owners and Buyers t = 6.4289 ; P > |t| = 0.0000 *Joint and Buyers: t = 3.3485; P > |t| = 0.0010*

Model B	All	Single owners*	Joint owners*	Buyers*
Mean TE	.859	.894	.859	.811
S.D	096	.073	.081	.118
Min	.414	.462	.553	.414
Max	.979	.979	.968	.958
Observations	326	115	123	88

Difference between means *(t-test): * Single 0wners and Joint owners: t = 3.3995 ; P > |t| =0.0008*
**Single owners and Buyers: t = 6.1281; P > |t| =0.0000 *Joint owners and Buyers: t = 3.5063 ; P > |t| = 0.0006*

Model A1	All	Single owners*	Joint owners*	Buyers*
Mean TE	**.848**	**.885**	**.842**	**.809**
S.D.	.097	.083	.088	.110
Min	.422	.422	.535	.481
Max	.982	.982	.967	.951
Observations	326	115	123	88

Difference between means *(t-test): *Single 0wners and Joint owners: t = 3.8748 ; P > |t| = 0.0001*
**Single owners and Buyers t = 5.6052 ; P > |t| = 0.0000 *Joint owners and Buyers: t = 2.4046 ; P > |t| = 0.0171*

Model B1	All	Single owners*	Joint owners*	Buyers*
Mean TE	.849	.883	.843	.812
S.D.	.098	.085	.090	.110
Min	.426	.426	.533	.484
Max	.982	.982	.968	.954
Observations	326	115	123	88

Difference between means *(t-test): * Single 0wners and Joint owners: t = 3.5099; P > |t| = 0.0005*
** Single owners and Buyers: t = 5.2083; P > |t| = 0.0000 * Joint owners and Buyers: t = 2.2708 ; P > |t| = .0242*