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Keywords: Stochastic Frontier Production, Technical efficiency, Groundwater, Sugar cane, India

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1. Introduction

Accompanied by the introduction of high yielding varieties of crops and fertilisers, irrigation has substantially altered the agricultural profile of India. Since independence, India's gross irrigation potential has increased nearly five-fold, from 19.5 to 95 million hectares in 1999-2000 (Government of India, 2002a). Over the same time period, foodgrain production increased from 50 million tonnes (mt) to 208 mt (ibid). Such an achievement has not come without its costs. The Green Revolution of the 1960s heralded a new phase for the country, by transforming the nation from a food deficit to a food surplus nation. The regional spread of the revolution was uneven, with north India (in particular Punjab and Haryana) leading the way.

More than 90% of available water in India has been used to meet the irrigation needs of the country, leaving 10% for industry and the domestic sector. The utilisation of groundwater sources has played a key and expanding 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, e.g. in Uttar Pradesh, net irrigated area by private tubewells grew from 48 thousand hectares in 1960-61 to 5095 hectares in 1984-85 (Le Moigne et al., 1992). The State of UP has played a pivotal role in this rapid expansion through its rural electrification programmes, availability of credit, and subsidies for investment in wells and pumps. 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 sugar cane and paddy, has led to a surge in tubewells.

In this milieu, 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, has provided an incentive to construct tubewells. The distortion in groundwater markets produced by subsidised electricity and diesel oil has led to over extraction of water: demand has grown unchecked and with it supply has been augmented (although it has not kept pace with demand). For the resource, this has meant a decline in water tables and a threat to its sustainability and to the viability of agricultural production and farmers' livelihoods.

An expanding population and a growing economy demand not only a more equitable distribution of water but also a more efficient use of it, which is particularly compelling in irrigation. For the agriculture sector, this would translate to an increase in the productivity of all inputs at the farm level, especially a scarce resource such as water. For water this translates to increased yields per unit consumed, as well as increased efficiency in the use of water that complements other inputs used in the production of crops.

2. Research Objectives

This research study looks at the structure of water markets and its effects on production efficiency by farmers in the north Indian state of Uttar Pradesh, over the two agricultural seasons–*kharif* (monsoon) and *rabi* (winter). Specifically, this paper looks at technical efficiency in production across a cross section of farmers and amongst farmers by category of water users. The analysis is aided by an examination of water markets and the patterns of water use and its exchange amongst farmers. The analysis is based on a survey conducted in the village of Tamelagarhi located in a 'dark block' area[1], where farmers rely solely on groundwater for irrigation and where the growth of tubewells has taken place unfettered. The study focuses on the production of sugar cane, which is widely grown by the farmers that were surveyed. The study of water is particularly relevant for the sugar cane crop as it is water-intensive requiring approximately 15 irrigations annually. Thus, water is fundamental to sugar cane growth. In addition, sugar cane is a lucrative crop for farmers to grow compared to the wheat, paddy and other crops commonly grown in the area. This research is motivated by the declining water tables in the region due to the proliferation of tubewells, and by the corresponding responses of farmers to their specific economic and water environment.

The structure of water markets will allow an analysis of how groundwater is exchanged between farmers and the market and non-market factors that influence this exchange. Market structure, such as the density of tubewells, density of market players, number of transactions, and water charges, is expected to influence exchange and volumes demanded. Non-market factors, such as electricity supply, are expected to influence the volume of water actually used

[1] Dark Block is defined as the stage of groundwater development where use exceeds 85% of annual replenishable recharge. Other categories are 'grey blocks' and 'white blocks defined by the state of groundwater development which uses between 65%-85% of annual recharge and less than 65% of annual recharge respectively (Government of India, www.india.gov.in). In Uttar Pradesh (UP), out of a total of 819 blocks, 85 are 'dark blocks' and 214 are 'grey blocks' with 67 of the dark and 86 of the grey blocks lying in the western region of the state (the village of Tamelagarhi is located in western UP) (http;//irrigation.up.nic.in).

by tubewell owners and supplied to buyers. Other factors, such as land fragmentation and social norms and customs are expected to influence transactions amongst farmers. 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.

There are several arrangements observed in the field for access to water. The most desirable arrangement is the independent ownership of a tube well, which permits both a ready access to water for cultivating own plots as well as surplus which can be sold to other farmers. 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. The benefits to ownership include timeliness of water delivery and higher yields and profits. The privileges conferred by access to water are expected to influence efficiency of sugar cane production arising from the interaction of water resources with other inputs. Further, these privileges include the indiscriminate water use by owners arising largely from low operating costs of running a tubewell due to subsidised electricity charges and flat rate tariffs, a common government policy for the agricultural sector.

2.1 Technical Efficiency

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

Using parametric approaches to production, technical inefficiency across sugar cane growing plots is estimated using an output-oriented measure. Specifically, a stochastic production function is employed and inefficiency scores for farmers at the plot level are calculated. Technical inefficiency obtained in this manner is a *relative* measure where the production frontier is defined by the farmers' plots included in its estimation. The determinants of inefficiency are then analysed using farmer-specific explanatory variables that are expected to influence it.

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 output production, especially for water, 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, and thus use their inputs more efficiently than tubewell owners who face near zero marginal costs of using water due to flat rate electricity pricing and who enjoy a more controlled access to water.

The literature has focussed to a large extent on the political economy and the economic structure of water markets and less so on efficiency issues stemming from access to water. This study instead examines the distributive equity of water markets by examining irrigation patterns and output on plots for farmers who buy water compared to those who 'own' their water, thereby questioning the equity framework[2] founded on private investment in groundwater. An examination of technical efficiency across the three categories of farmers will have implications for the current supply driven policies, such as the existing groundwater laws and electricity pricing that encourage private investment in the extraction of water. Survey results will be pertinent for areas similar to the surveyed village.

3. Literature Review

There are many studies on groundwater where the distribution of the resource has been examined on issues ranging from social norms to economic drivers. Shah (1993) has been at the forefront in the analysis of groundwater markets, and has highlighted the benefits of markets over public works in terms of the greater and more equitable access they give to

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

small farmers. Characterising them as “spontaneous, informal, unregulated, localised, fragmented, seasonal and impersonal,” Shah documents a variety of payment systems that are in place, ranging from kind-based in the formative stages of the water market to purely cash-based transactions in a mature market. Due to the lumpy nature of investments, 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 further encourages the distribution of water amongst farmers by providing greater access to it through greater market activity. However, its impact on water use inefficiency and sustainability are duly noted and Shah offers a suggestion to introduce incremental rates.

Responding to Shah’s work, Palmer-Jones (1994), Meinzen-Dick (2000) and Dubash (2002) have instead pointed to the inherent inequities that exist in these largely monopolistic structures and have highlighted the complexity in the nature of water contracts governed by social processes.

Palmer-Jones (1994) revisits the debate and questions as flawed the idea that treating groundwater markets as natural oligopolies, and shifting towards flat rate pricing will propel these economic systems towards a more competitive market and mitigate their monopolistic nature. Instead Palmer-Jones suggests that 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. The suggestion put forward by Shah to introduce rationing of “high quality” power to counter the race to the bottom is questioned by Palmer-Jones, who does not find evidence of such a policy in place.

Meinzen-Dick (2000) takes Shah’s work a step further and provides justification for joint ownership of tubewells over pure purchases. Examining the case of Pakistan, Meinzen-Dick finds that more than half of the water purchasers did not get their water when requested. Further, analysing the determinants of reliable supply, the author finds better service for older and larger landowners and from diesel driven tubewells. Meeting each of these options - age, larger landholding and switch in technology - is expensive (or infeasible) and the author suggests expanding tubewell ownership to medium sized farmers, where the disparity between water purchasers and sellers will be less than between single tubewell owners and water buyers in terms of status and landownership. The author reiterates Shah's point that water markets do provide small and poor farmers with an alternative but that the benefits disproportionately favour tubewell owners who only provide water when they do not need it themselves. In an another study, Pant (1995) demonstrates the impact of untimely supplies of water on output and highlights further the disadvantages to the water purchaser and the inherent inequities in the water market.

Janakrajan (1994) provides insights into the market conditions prevailing in groundwater transactions in four districts in Southern Tamil Nadu covering 27 villages. The author finds variations in pricing both within and between villages and highlights the inequity amongst sellers and water buyers, with the former becoming centers of power in the village. The interlinkage of water markets with labour and product markets is observed, with the latter often sold at below market price to water suppliers. This further raises the price of water to buyers and points to the inequity existing in water markets.

Jacoby, Murgai and Rehman (2004) look at the allocation of water across farmers in the Punjab in Pakistan. Their study examines the extent of price discrimination in groundwater markets, where high investment costs and credit constraints influence installation of private tubewells, and conveyance losses enforce monopoly power of the seller. Water markets are closely linked with other rural markets and the authors observe their interaction with tenancy contracts. Their findings on price discrimination reveal a bias towards tubewell owners' tenants over pure buyers, thus confirming the interlinkage between water markets and other rural markets. Alongside, they look at a parallel market in canal waters and which, their findings suggests, alleviate some of the inefficiencies in water allocation stemming from monopoly power in groundwater.

Based on a comparative analysis of two groundwater dependent villages in North Gujarat, Dubash (2002) examines the intricate relationship between the resource and the institutions that evolved around it, the complex nature of contracts between water buyers and water sellers and the role that society plays in shaping the outcomes across its different segments. The exchange of water in the two villages is studied using three helpful indicators, "market architecture"–the density of tubewells; "market thickness"–density of exchange and the terms of payment; and the "terms of exchange." Dubash finds considerable variation in groundwater exchange in the two villages measured by the first two indicators. What is even more revealing is the multiplicity of contracts governing sales which may assume a flat cash price per hour, a fixed share per acre for tenants or a percentage share of the crop. The terms vary by crop and by season thus adding another dimension to the existing and rather complex pricing structure. *The price charged is uniform across buyers* and *does 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 will be different by technology such as by type of tubewell). Dubash's work is unique in that it analyses groundwater markets in a static framework in the two villages but also records the changes or lack thereof it over time. He thus finds the terms of exchange to have a certain permanence to them which cannot be explained by market models (neither by competitive models or fragmented duopoly models) but by social processes and institutions that govern the exchange. (In the surveyed village, prices charged are closely and positively correlated with the electricity price[3] but the actual price is determined where the market is the thinnest, i.e. in the east, and which then is uniformly adopted by the rest of the market players)

Pant (2004) traces the evolution of water markets in eastern and western Uttar Pradesh. His findings are particularly relevant to this study as his observed surge in investment in privately owned tubewells and in demand for electricity is also apparent in the surveyed village of Tamelagarhi. The surge is attributable to the demands placed by the high yielding variety of seeds and the consequent need for timely and reliable water supply coupled with farmers' drive to maximise yield. The growth increased the demand for power, which while available in plenty in the 1970s, now became a constraining factor, *a fact which is reflected in the surveyed village*. Transactions in groundwater are noted for their importance in elevating the position of the small farmer by providing access to water. Equally important has been its role in meeting the challenge posed by scattered land holdings, *a phenomenon observed in the surveyed village*.

A notable exception is the work of Vaidyanathan and Sivasubramaniyan (2004) who have attempted to calculate the efficiency of production and in water use for different crops and in different agro-climatic regions of India. The authors have calculated technical efficiency of water (defined the ratio of consumptive use to gross irrigation supplies) at the basin level and

[3] Since this study is based on cross sectional data, no information on previous years' electricity prices and water prices was collected. However, during the survey, anecdotal evidence from farmers was obtained which revealed that when electricity prices increased, so too did water charges.

production efficiency (defined in terms of value of output per hectare for irrigated and unirrigated areas) for several states. Their results show that basin level technical efficiency varies between 25 to 50 percent. Further, output per hectare while higher on irrigated area than rainfed area, yields per unit of consumptive use (defined as the evapo-transpiration needs of crops) are not as a rule higher and in fact are 10 to 30 percent lower than unirrigated area. However, their work does not disaggregate by groundwater or surface water sources. The authors were not able to provide explanations for their findings due to limitations in data accuracy, and due to the varied nature of production arising from cropping patterns, rainfall patterns and other regional factors. The authors suggest a more disaggregated analysis-an approach adopted in this paper.

This paper adds to the existing body of literature examining the functioning of water markets in different parts of India and the inter-relationships between the various actors conditioned by hyrodology (i.e. the level of groundwater and the expanse of water aquifers). This paper estimates efficiency in production of a lucrative and water thirsty crop using the stochastic frontier production model in a farm production setting characterized by different water ownership types and where there is sole reliance and virtually unrestricted access to groundwater. Further it examines factors causing inefficiency and integrates the nature and political economy of water markets to explain the observed efficiency differentials. It is thus both a deviation from the literature reviewed as it utilizes the frontier approach to estimate efficiency in production as well as and addition to the literature by synthesizing the functioning of water markets that explain differentials in efficiency.

4. The Village Survey: Tamelagarhi

4.1 General Description

The village of Tamelagarhi is located in the north Indian state of Uttar Pradesh (UP), which shares its borders with nine other states and the country of Nepal. Thirty one percent of the population in UP falls below the poverty line (Government of India, 2002) and 57.36% of the population is literate (only three other states have literacy rates that are worse than UP). Agriculture constitutes the backbone of the Uttar Pradesh economy by employing 72% of the total workforce and contributing to 33.4% of the state's GDP. Irrigation is an important agricultural input and irrigated land covers 67% of the total agricultural area. UP is India’s largest producer of foodgrains, wheat, and sugar cane.

The first state-sponsored public tubewell was installed in the 1930s in the district of Moradabad. Since the first Five Year Plan, there has been a steady increase in the number of state tubewells and a corresponding decline in their gross cropped area. By the end of the 1980s, there were 24,000 state tubewells and the gross cropped area stood at 35 hectares for each tubewell, down from 153 hectares in 1966-67 (Pant, 2005). At the same time Uttar Pradesh has also witnessed a steady increase in the number of privately owned tubewells from 3000 in 1951 to over a million by 1980 (ibid). Commensurate with the growth of groundwater extraction has been a fall in water levels. Of a total of 1028 observation wells, 823 experienced a decline in water levels, with more than half documenting a decline of 2 meters over a three-year period (between May 2000 and 2003)[4]. Such figures do not augur well for groundwater resources in Uttar Pradesh especially in areas where groundwater is the primary source of irrigation, such as in the surveyed village of Tamelagarhi.

4.2 Study Area

The data were collected in the village of Tamelagarhi (about 200 km from the capital of Delhi) in Baghpat district. The village is 3 kilometers from the nearest surfaced road. Roads to and within the village are unsurfaced and are lined with open drains. There are approximately 300 households in Tamelagarhi, of which 165 are farming households with agriculture as their principal occupation.

Sugar cane is the main crop grown in the village. Other crops grown are wheat, *jowar*[5] and green lentil. The sugar cane crop is an annual crop and is grown primarily for sale to the neighbouring sugar mills. Conversely, wheat, *jowar* and green lentil are often used for home consumption. There exists a proper chain for sugar cane production from the time it is grown to the point where it used by industry for distribution to consumers. Sugar cane deposit centers are present at several spots in the village. The freshly harvested crop is then picked up by trucks and transported to the neighbouring sugar mills.

The official electricity schedule promises ten hours of continuous supply and follows a weekly rotation with one week of supply in the night followed by daytime supply. However,

[4] Rajya Sabha Unstarred Question No. 2227. Government of India, www.indiastat.com
[5] Sorghum

during the summer months supply is erratic and averages six hours a day, often with frequent interruptions. During the survey round, electricity 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. Water supply for domestic consumption is ample, with hand pumps dotting the village at a distance of 50-70 meters. The countryside is similarly dotted with tubewells, with a higher concentration in the northern side of the village. A river flows in the eastern side of the village but appears to be polluted, possibly due to the effluents discharged by the neighbouring sugar mills. There are no canals running through the village, although construction of a minor canal is in process.

The village of Tamelagarhi falls within the 'dark block' area, which is typically characterised by declining levels of groundwater. When asked about the level of groundwater, farmers confirm that water has indeed been declining and cite the spurt in tubewells as the main reason. What is unsaid and observable is the fragmentation of land and the subsidised 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 replenishisng 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 looking for. True to its peculiar nature, the aquifer is a common property resource which anyone can tap into, whereas water is a private good and is extracted by those who own land above it. There are no laws, neither government nor informal, on how much can be extracted. 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.

4.3 Survey Rounds

The first round was conducted in mid-May 2004 with a census of all land-owning farming households in the village. In the census, a total of 165 farming households were interviewed, with details on basic demographics, land ownership, crops grown, tubewell ownership, and water transactions. In addition to the households surveyed, there are other agriculture labour-providing households which were not included in the survey. In essence, the majority of households in this village derive their livelihood from agriculture. Following the census, a random sample of tubewells, which formed the primary sampling unit, was drawn to start the first survey round. The village was divided into four directions -- north, south, east and west -- from which a total of 78 tubewells were randomly chosen in proportion to their density in each direction. Of these 78 tubewells, more than half belong to single owners with the remaining being jointly owned, usually between brothers. For each tubewell in the survey, information on the plots it serviced was obtained. These amounted to 350 plots (which after data cleaning were reduced to 326) and were 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. The actual payment was made in half yearly, yearly or end-of-season installments. Following the first round, a second survey was conducted in mid August 2004 to which details on other inputs, notably natural manure, chemical fertilisers, weedicides and insecticides were added. Details on tubewell specifics were obtained in the third round of the survey, conducted in September 2004. These were important for capturing variations in the supply to each plot as well as to calculate the effective water rates charged to each buyer. In the following month, in addition to the usual questions on irrigation, information on labour input for all stages of the crop was obtained. Labour input included own family labour, hired labour and contractual labour. In November, consultations were held with the National Bureau of Soil Survey and Land Use Planning (NBSS&LUP) at their regional centre in Delhi to facilitate the soil testing process that was conducted soon after. From January to April 2005, harvest data for all plots for both types of sugar cane was obtained. The process was gradual as farmers were pressed for time and were often not found at home. Discharge data were collected in the month of May 2005. Using a plastic 150 litre container, a flexible tube, rope and a stopwatch, discharge data was collected. For each tubewell, two measurements were taken and then averaged. The final round was conducted in the last week of May 2005 and was termed the household roster round. The objective of this last survey was to obtain some basic demographic and household data.

In the course of the survey a village map (*sijda)* was obtained from the *patwari* or irrigation official to mark the location of each of the 78 tubewells at the plot level. An identity was assigned to each tubewell using the plot numbers (*khasra numbers)* that were already marked on the map. The location revealed a rather even spread of tubewells, though there were fewer in the western and southern locations than in the northern and eastern side. The village habitation lies close to its southwestern border, leaving little room for cultivation and concentration of tubewells. The largest expanse of land lies to the east of the village which is bifurcated by the river. To the east of the river lie large low-quality lands where water can be supplied by pumping water from the river. The lands to the east of the river are noticeably larger in area per plot arising due to the inferior quality of land. Land close to the river is characterised by sandy soils. A description of some of the summary statistics is presented below.

4.3.1 Tubewells

In the survey, 78 tubewells were selected and formed the primary sampling unit. Plots served by each of these tubewells were identified and were primarily of two types, those belonging to the owner (single or joint) and those to which water was sold. The tubewells surveyed were of two kinds: submersible and non-submersible, with the former being deeper than the latter. Of the 78 tubewells, 32 were submersible and 46 were non-submersible. 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 (Table 1). This is expected as water sold is surplus to the needs of the owner farmers. However, investment in a tubewell is not viewed as an enterprise to profiteer from but rather as an essential input to the farmer's sugar cane crop. 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, 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 with buyers' plots and those at the end of the rotational cycle for jointly served plots being the last in line to receive water.

Table 1: Distribution of Water by Tubewell Ownership

	Single Owner Tubewells	Joint Owner Tubewells
Average no. of own plots irrigated	2.4	6.2
Average no. of buyer's plots	1.7	0.6
Percentage that sell water	55%	35.7%

4.3.2 Irrigation

Of the 326 plots, 38% received water from jointly-owned sources, 35% from singly-owned water sources and 27% received bought water. Average area served was the largest for singly-owned water sources with the smallest being for bought water plots. This is not surprising, as farmers with larger plots of land (and hence wealthier farmers) derive the greatest benefit from investment in tubewell technology and from better access to a secure water source. The largest plot area of 50 bighas was also served by singly owned tubewell water source and the least area was serviced by a purchased water agreement.

A bimodal measure of flooded irrigation (i.e. a yes or no response to having received flooded irrigation) summed across the first seven irrigations is taken as the first indicator of good water flow.[6] Of the singly-owned tubewell plots, 110 or 96% reported having flooded irrigation for the first seven irrigations (Table 2). The corresponding numbers for joint tubewell plots and bought water plots is 86% and 75%.

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

Table 2: Irrigation by water ownership type

	Singly-Owned Tubewell Plots	Jointly-Owned Tubewell Plots	Bought Water Plots
No. of plots served	115	123	88
Average area served (bighas)	11.7	6	4.6
Maximum area served (bighas)	50	35	16
No. of plots with flooded irrigation across first seven irrigations	110	107	66
No. of plots with first 5 irrigations before start of monsoon (31 July)	84 (73%)	73 (59%)	32 (36%)
Mean height 1st irrigation (inches)	2.83	2.61	2.66
Mean height 2nd irrigation (inches)	2.77	2.61	2.62
Mean height 3rd irrigation (inches)	2.75	2.63	2.59
Mean height 4th irrigation (inches)	2.74	2.68	2.75
Mean height 5th irrigation (inches)	2.97	2.91	2.71
Mean height 6th irrigation (inches)	2.93	2.90	3
Mean height 7th irrigation (inches)	3.02	2.89	2.91
Mean height 8th irrigation (inches)	3.08	3.08	3.03
Mean height 9th irrigation (inches)	3.11	3.08	2.87
Mean height 10th irrigation (inches)	3.11	3.06	2.79
Average lag between 1st & 2nd irrigation	25	27	34
Average lag between 2nd & 3rd irrigation	19	22	27
Average lag between 3rd & 4th irrigation	20	21	23
Average lag between 4th & 5th irrigation	21	22	31
Average lag between 5th & 6th irrigation	22	24	29

A maximum of 15 irrigations was recorded over the entire cropping season for sugar cane, with only six plots receiving all 15. Of these six plots, four received water from singly-owned sources and two received water from jointly owned sources. Only two of the bought water plots received a maximum of 13 irrigations. Further, across the three categories of plot by water type, only 36% of bought water plots were able to complete 5 irrigations prior to the start of the monsoon season, whereas 73% of singly-owned water plots were able to do the same.

The mean depth of irrigation, recorded in inches by the farmer, favours singly-owned water plots consistently over all irrigations. The first few irrigations are crucial for the growth of the sugar cane crop. From the table above, the difference in mean height of flooded irrigation is slightly higher for the first three irrigations between owned water plots and purchased water plots.

Timing of water supply is crucial for plant growth, and sugar cane is no exception to this. It is vulnerable to lack of water in the early stages of its growth, which also coincide with the driest months. Using average gap between irrigations as a variable for timing, the data suggests that singly-owned water plots were more regularly and frequently irrigated (and closely followed by jointly owned water plots) than plots where water was bought. This is not surprising as the greatest benefits in terms of groundwater access lie with their owners. Erratic electricity supply, which was particularly high and infrequent in the summer months of June and July, works against the interests of the farmer buying water as he only receives it in surplus to the water needs of the tubewell owner, thus contributing to this lag between successive irrigations.

Using three indicators for the volume of water–mean depth, average gap in irrigation days and timing of irrigations–as proxy indicators for the volume of water, the overall picture that emerges shows that water application for singly-owned water plots is higher than those for purchased water plots. Hence, farmers buying water are deprived of it on all three counts.

4.3.3 Labour

For the sugar cane crop in Tamelagarhi, farmers used labour inputs at various stages in the life of the sugar cane plant and for different activities. Data for labour were collected across several categories observed in the surveyed village, namely hired casual labour, hired permanent labour, labour provided in exchange, hired contractual labour and own household labour. The first four categories differ in their terms of employment. Thus, hired casual labour is employed on a daily basis. Hired permanent labour is employed on a monthly basis and is given cash wages plus clothing, food and shelter. Usually, permanent labour is hired for a period of eight to nine months from end-August or early-September to May of the following year. Labour in exchange is unpaid labour and is a mechanism by which own household members work on a farmer's field, which is later reciprocated. Hired contractual labour involves a company of labourers who are employed for a job (such as harvesting or weeding an entire plot). Wages are paid for the entire activity and distributed amongst them equally. Frequently, members of the household also work on their own fields, especially for buyer plots or for certain types of activities, such as was observed for fertiliser application..

Disaggregating labour by type of plot, it is observed that labour is most intensely used on bought water plots (Table3). Substitution of labour effort for irrigation on these plots cannot be ruled out as labour can be used more intensively to make the most of a scarce, priced and often delayed input of water which is heavily influenced by the electricity schedule.

Table 3: Labour intensity across plots

Hours per bigha	Singly-Owned Tubewell Plots	Jointly-Owned Tubewell Plots	Bought Water Plots
Average Labour	170	188	191
Average Irrigation Labour	0.6	0.7	1
Average Harvest Labour	141	158.5	161
Average Fertiliser Application Labour	4.9	4.9	5.7

4.3.4 Harvest and Yields

Sugar cane is an annual crop, the life of which spans three years. Sugar cane yields increase over time and after three years are replaced by the fresh shown or non-rattoon crop. The sugar cane 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 availability of labour and the demand for sugar cane from the neighbouring sugar mills. Each farmer supplies sugar cane according to what is required by the sugar mills. The rest of the crop remains standing on the field.[7] Each farmer receives vouchers from sugar mills specifying the quantity of sugar cane that he can deposit. The sugar cane is deposited in nearby deposit centers from where it is transported in trucks to the mills. The sugar mills thus influence the timing of the cutting of the sugar cane harvest. Harvesting is a very labour intensive process and requires labour for cutting, stripping of leaves and loading onto bullock carts.

Two types of sugar cane are grown in the village: early variety and general variety. The two varieties are known to differ in their sugar content and command different prices. Early variety is sweeter than the general variety and fetches a higher price. Each sub plot was further apportioned by the sugar cane variety grown on it. However, yields and input use do not vary across the two varieties. Out of a total of 326 plots, 33 plots grow early variety and 203 plots grow general variety of sugar cane. On the remaining 90 plots, both varieties are grown.

[7] Yields for the standing crop keep increasing until March by which time the farmer must get rid of his sugar cane to avoid a decline in sugar content.

Harvest data was thus collected for each plot, for each variety of sugar cane. The data were collected in the manner that was most convenient to the farmer. Hence, it was divided into two: the part that went to the sugar mills and the remainder that was sold privately-usually to other farmer entrepreneurs-for *jaggery* making. Harvest estimates were thus summed up across these two divisions to arrive at total harvest. While yields could be obtained for mono-variety plots, for mixed plots, i.e. those that grew both varieties, another method was adopted to arrive at aggregate yields (See Appendix A for aggregation). This was done because area data referred to the entire plot and was not specific to the area of sugar cane variety. Harvest data was then aggregated across the two varieties to arrive at average yields for the sugar cane crop.

Survey data show that for singly owned tubewell plots yields were 58 quintals per bigha, on jointly owned plots yields were 58.6 and on bought water plots yields were 53.2 quintals per bigha. 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.

5. Economic Efficiency and the Frontier

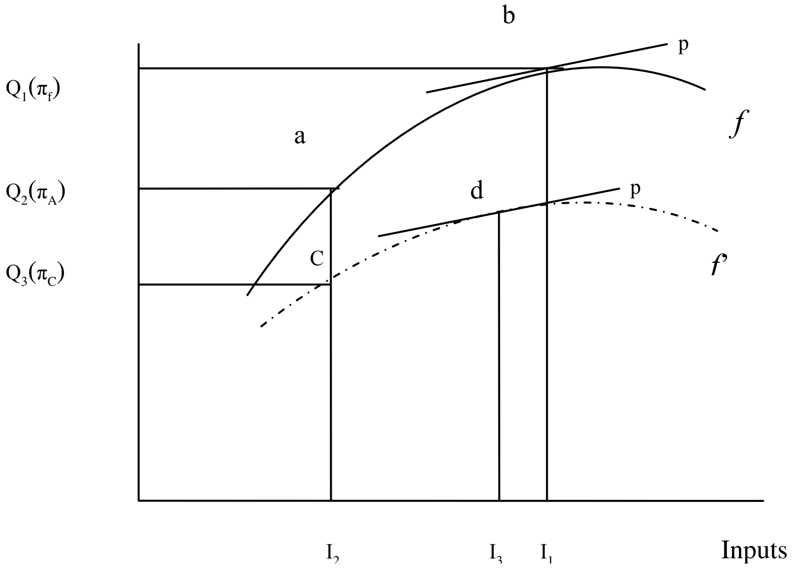
Economic efficiency is described by its component parts: technical efficiency and allocative (price) efficiency. A farmer is more technically efficient (TE) than his counterpart if he produces a higher output from a similar bundle of inputs. Allocative efficiency (AE) is reached when the marginal cost 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), Afriat (1972), Aigner, Lovell and Schmidt (1977), Meeusen and van der Broeck (1977), Kumbhakar and Lovell (2000) and Reinhard et al (2002).

The concept of production frontiers and efficiency can be illustrated with the aid of Figure 1, using output (Y axis) and inputs (X axis). Here an output oriented measure of efficiency is described (Kalirajan and Shand, 1999). The production frontier for a firm using best practice techniques is shown by frontier *f*, which in the context of this paper represents the stochastic production frontier[8]. A firm operating at point b on the frontier receives profit $_f$, where the price line *p* is tangential to its production frontier. At this point the firm is economically

[8] The stochastic production frontier is represented by Y=f(X,β)exp(*v*) which vacillates around the deterministic frontier (not shown in the figure) described Y=f(X,β)

efficient and there is neither technical nor allocative inefficiency. If on the other hand, the firm operates at point *a* on the frontier, it receives lower profits $_A$, arising due to allocative inefficiency given by $_A/\ _f$.

Figure 1. Production Frontier: Output Oriented*



**Kalirajan and Shand,, 1999*

In reality however, firms do not operate at their best practices output curve *f* but rather at a lower frontier *f'* due to various constraints such as inappropriate or outdated production, organizational constraints and non-price factors such as information glitches. These factors can cause a firm to operating at a point such as *c*, using an input bundle I_2 and receiving lower profit $_C$. At point c, the firm experiences both allocative and technical inefficiency. A movement to point production at *d*, would leave the firm allocatively efficient but still technically inefficient as output levels could be raised further to levels at frontier *f*. In terms of output loss, a firm operating at c, experiences a shortfall in output given by Q_1-Q_3. Of this total shortfall, Q_2-Q_3 is attributable to technical inefficiency and Q_1-Q_2 is attributable to allocative inefficiency.

6. Estimation Methods and Techniques

There are various approaches to measuring efficiency, which can be categorised into parametric and non-parametric methods. The difference between the two lies in the specification of a functional form, *a priori*. While parametric methods are restricted to a functional form, non-parametric methods rely solely on sample observations that are used to construct a production frontier. Non-parametric methods, as originally conceived by Farell, used the unit input output space to create a frontier isoquant within the production possibility set. The frontier was determined by a single or a convex combination of efficient units which were then compared against inefficient units to calculate the extent of inefficiency. This method was later applied to the multiple input output case (Murillo-Zamorano, 2004).

Parametric techniques are further classified into deterministic and stochastic methods. Deterministic methods date back to Farell's (1957) seminal work, where he introduced the idea of parametric methods using the Cobb-Douglas production function to estimate a convex hull of observed input and output ratios. His suggestion was further developed and tested by Aigner and Chu (1968), Afriat (1972), and Richmond (1974). Both Aigner, Lovell and Schmidt (1977) and Meeusen and van der Broeck (1977) independently introduced stochastic production frontiers, where each firms' frontier is bounded above but is allowed to vary across firms. Hence, each firm's efficiency is measured relative to its own frontier rather than to some industry wide frontier. In essence, the difference between deterministic and stochastic methods lies in the treatment of the error term. In deterministic methods, the error is implicitly assumed and makes no distinction between unobserved variables that lie outside the control of the agent and those that lie within it. Stochastic models decompose the error term into purely statistical noise (that lies outside the control of the production agent), and inefficiency (a one-sided error term). Parametric methods such as the stochastic production frontier method offer an opportunity to researchers to test their hypotheses, but restrict them to certain production relations assumed by the functional forms employed.

Several estimation techniques exist to estimate or calculate the efficiency frontiers. These are mathematical programming techniques or econometric estimation methods. Deterministic parametric methods employ either mathematical programming techniques (Aigner and Chu, 1968) or econometric estimation techniques. Stochastic parametric methods employ only econometric techniques such as Maximum Likelihood Methods or Corrected Ordinary Least Squares, that are used to estimate rather than calculate the efficiency frontier (Kumbhakar and Lovell, 2000). Non-parametric methods such as the Data Envelope Analysis (DEA) rely on mathematical programming applied to sample observations to construct a production frontier and which are used to calculate efficiency scores. The advantage of the DEA method lies in its flexibility as it requires no specification of a functional form. However, it is entirely data driven and extremely sensitive to outliers. Also, it does not allow the estimation of shadow prices nor does it allow testing of hypotheses.

In this paper, the stochastic production frontier, using regression techniques, is employed to estimate technical inefficiency in production at the plot level using primary survey data. Agricultural production is often susceptible to the vagaries of nature which lie outside the control of the farmer, and in this specific instance, water availability is a highly stochastic input.

6.1 Methodology: Parametric Production Frontiers

The production function for a firm producing a single output and using multiple inputs following the best techniques can be described by the neoclassical production function (Kalirajan and Shand,1999):

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

where Y^*_i and Xi are output and inputs at the frontier of the *i*th firm, β 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 price or allocative inefficiency. In practice however, firms may not be operating at the optimum due to socio-economic constraints, information gaps and non-price factors, all of which prevent them from utilizing their inputs optimally. In such case, a slackness in production is represented by modifying the neoclassical production function to represent possible technical inefficiency and a deviation away from best practice production. The production function of the *i*th firm is thus described by:

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

where TE_i represents technical inefficiency of the *i*th firm due to which units operate at a level below the maximum obtainable output levels from inputs utilised. 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, else it is < 1. In the description above, TE_i is an output oriented measure of technical inefficiency and can be defined by:

$$TE_i = Observed\ Output\ /\ Maximum\ attainable\ output = Y_i\ /\ Y^*_i$$

or $$TE_i = Y_i / f(x_{i1}, x_{i2} \ldots x_{im}, \beta)$$

where $f(x_{i1}, x_{i2} \ldots x_{im}, \beta)$ represents output at the frontier.

In the expression above, only values of output captured in the numerator are observed, while TE_i measures the departure of the numerator from the denominator, which is not observed. There are various ways to measure TE_i and thereby the denominator which represents best practices. These methods are based on different assumptions, and the choice depends on how strong each of the assumptions is with respect to the economic environment in which the unit operates. As described in the previous section, parametric methods employ deterministic and stochastic models. The deterministic models assume that all factors affecting production are under the control of the decision-making unit. Hence, the deviation observed between the frontier and observed output levels is ascribable to technical inefficiency, captured by TE_i. However, there are some factors that affect production and which are not in the control of the production unit such as weather, information gaps, socio-economic factors, 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

$$Y_i = f(X_i, ; \beta)\ exp(\varepsilon_i = v_i - u_i) \quad \text{with } u_i \geq 0; \tag{1}$$

where Y_i represents output on the ith plot ; X_i are the input variables associated with the ith plot; β 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. u_i is *iid* and is obtained as truncations at zero of the normal distribution. Both v_i

and u_i are independently distributed of each other. Using equation (1) technical efficiency is defined as

$$TE_i = Y_i \,/\, f(X_i, ; \beta)\, exp(v_i)$$

$$= f(X_i, ; \beta)\, exp(\varepsilon_i = v_i - u_i) \;/\; f(X_i, ; \beta)\, exp(v_i) = \exp(-u_i) \quad (1')$$

where $f(X_i, ; \beta)\, exp(v_i)$ is the stochastic frontier output

$$v_i \sim N(0, \sigma_v^2) \quad (2)$$

$$u_i \sim |\, N(0, \sigma_u^2)\,| \quad (3)$$

For the inefficiency terms, there are a number of assumptions to their distribution for example normally distributed, exponential, truncated normal, and normal gamma. Fuwa, Edmonds and Banik (2005) and Kumbhakar and Lovell (2000) show that qualitative estimates are not sensitive to the type of distributional assumptions made. However, quantitative estimates are sensitive but their rankings do not change across the different distributions. This represents a current lacuna in the literature on efficiency analysis as there is no consensus on which distributional form to use. The half normal distribution has been widely used in the efficiency literature.

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 shown in equation (4).

$$u_i = Z_i\, \delta + W_i \quad (4)$$

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 in equation (3) such that W_i • - Z_i δ 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. This can be done either in a single step or in two steps. Battesse and Coelli (1995), use the single step procedure, which 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 (4). In the two step procedure[9], the obtained technical inefficiency scores are further regressed as an independent step on explanatory variables usually by incorporating a limited dependant variable estimation method, since the TE scores lie between 0 and 1. However, the two stage procedure has been criticized with respect to the assumptions made regarding technical efficiency in the first stage, viz., they are independently and identically distributed. This assumption would be contradicted if these efficiency estimates are regressed on explanatory variables as *iid* would no longer hold and a causal relationship between efficiency estimates and the right hand side variables is assumed (Kumbhakar and Lovell, 2000).

In this paper, the one step simultaneous procedure is applied and is a variant to the Huang and Liu [10] 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 Battesi 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 size of plot. Inclusion in the latter is motivated by farmers primarily being driven by size of their plots to invest in tubewell technology.

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[9] see Reinhard et al (2002) for a refined exposition where they follow the two step procedure without violating the assumptions.

[10] Huang and Liu's (1994) model is characterized by a technical efficiency 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) .

Technical efficiency is thus obtained from equation (1) and equation (4) using the method of maximum likelihood estimation to estimate

$$TE_i = \exp(-u_i) = \exp(-Z_i\,\delta - W_i) \mid \varepsilon_i \tag{5}$$

Since u_i is non negative, TE scores are bounded between 0 and 1 as $0 \leq \exp(-u_i) \leq 1$. TE scores are obtained from the expectation of u_i conditional on the observed value of ε demonstrated by Jondrow et al (1982) for the half normal distribution of u_i[11]. Using maximum likelihood estimation methods technical efficiency is estimated for each unit of observation. In addition, the coefficient vector β for the X_i inputs, and parameter estimates, , of the Z_i covariates, and the variance parameters σ^2 and λ defined as [12]:

$$\sigma^2 = \sigma_u^2 + \sigma_v^2 \tag{6}$$

$$\lambda = \frac{\sigma_u}{\sigma_v} \tag{7}$$

are also estimated. Battese and Corra (1977), instead suggest using parameter γ in equation (8), which lies between 0 and 1, and which can be searched to find a suitable starting value for an iterative maximisation process[13].

$$\gamma = \frac{\sigma_u^2}{\sigma_u^2 + \sigma_v^2} \tag{8}$$

where $0 < \gamma < 1$ (8')

The estimation technique applied is the maximum likelihood method which estimates for each plot, the technical efficiency scores by extracting u_i from ε_i (in equation 1). The process of estimation can be described in three steps. The first step involves the calculation of the slope coefficients and the variance. The second step involves the estimation of the likelihood

[11] Known as the JLMS technique, the method obtains the conditional distribution of u_i given ε_i :

$f(u_i \mid \varepsilon_i) = \dfrac{f(u_i, \varepsilon_i)}{f(\varepsilon_i)}$ where $f(\varepsilon_i) = \int_0^\infty f(u_i,\varepsilon_i)du$; $f(u_i, \varepsilon_i)$ is the joint density function for u_i and ε_i and $f(\varepsilon_i)$ is the marginal density function of ε_i obtained by integrating u_i out of $f(u_i, \varepsilon_i)$.

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

[13] On the other hand, λ can have any non-negative value.

function for several values of γ that lie between zero and one. The final step selects the best log likelihood values obtained previously as starting values for the iterative process to produce final maximum likelihood estimates (Coelli 1995).

To obtain parameter estimates, a functional form must be specified. In the efficiency literature, the Translog production function and the Cobb Douglas function have an overwhelming prevalence and the choice between the two is determined both by data as well as the objective of the research study being conducted. In this paper a test is conducted to verify the suitability of the Cobb Douglas versus the Translog production function. The Translog production function assumes the following form:

$$Y_i = f(X_{ij=1.....J}, ; \beta) = \alpha.\ \Pi_j^{\ J}\ (X_{ij=1.....J})^{\beta j} .\ \Pi_j^{\ J}(X_{ij=1.....J})^{\ ½\ [\Sigma \beta j\ LnXij\ ]}$$

In log form: $$Ln\ Y_i = \beta_o + \Sigma_j \beta_j\ Ln\ X_{ij} + ½\ (\Sigma_j^{\ J} \Sigma_K^{\ J}\ \beta_{jK}\ LnX_{ij}\ LnX_{iK}\ ) + V_i - U_i \qquad (9)$$

where $\beta_{jK} = \beta_{Kj}$ and $\beta_o = Ln\ \alpha$

The null hypothesis to test the suitability of the Translog versus the Cobb Douglas production function is captured by:

Ho: $\sum_i \beta_{jK,} = 0$ for all j, k = 1, …J. and over all plots i (10)

7. The Variables

Summary statistics of the variables used in the estimation of the stochastic production function is presented in Table 4.

Table 4: Summary Statistics of Variables Used in the Analysis

Variables	Mean	Std. Dev.
output (in quintals)	443.22	430.16
area (in bighas)[14]	7.49	6.21
labour (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[15])	105.69	107.32
irriafterr31july (bigha-inch)	116.83	113.25
Interact (labour*crop dummy, where crop dummy=1 if non-rattoon sugar cane, 0 for rattoon sugar cane)	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

8. Results and Discussion

A Wald test was conducted to test the suitability of the Translog Production Function (H_o: $\sum_i \beta_{jK} = 0$ from equation 9 and 10). The test is unable to reject the null and reveals that the Cobb Douglas is the appropriate model that explains the production process in the surveyed village. Further, the well known problems of multicollinearity were severely affecting coefficient estimates in the Translog function, thus reinforcing the Wald test in favour of the Cobb Douglas function.[16] An advantage of the Cobb Douglas production function is that coefficient estimates can be interpreted as measures of elasticity, thus

[14] One bigha equals one-fifth of an acre in this area.
[15] This is a volumetric measure where area of land measured in bighas was multiplied by height of standing water.
[16] The Wald Test statistic obtained equalled 0.60 with a probability value of 0.43 while the critical value for the chi-square was 3.84. Hence, the null hypothesis of zero higher order terms in the Translog production function could not be rejected.

allowing an analysis of the responsiveness of output to each of the input variables used in the production process.

Hypothesis tests on the suitability and validity of the efficiency model were conducted by employing the loglikelihood 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:

$$\lambda = -2\left[Ln \frac{L(H_o)}{L(H_1)} \right] = -2\left[LnL(H_o) - LnL(H_1) \right] \qquad (11)$$

where $Ln(H_0)$ is the loglikelihood value obtained from running the restricted model and $Ln(H_1)$ is the loglikelihood value obtained from running the unrestricted model. The test statistic, λ, follows a chi-square distribution with the number of degrees of freedom equivalent to the number of parameter restrictions imposed. The null hypothesis is rejected if the computed value of λ exceeds its critical value, otherwise we fail to reject it. All the tests are conducted using estimates from Coelli's frontier computer package FRONTIER 4.1 (Coelli, 1996). On the basis of these test results (shown in tables 5a and 5b), coefficient estimates of the stochastic frontier models are presented for frontier and inefficiency analysis (shown in tables 6a and 6b).

8.1 Hypothesis Testing

Five tests were performed to test the suitability of the frontier model incorporating inefficiency effects. The tests are performed for Model A and Model B (in Table 5a) which differ by the irrigation variable, which is split into two (pre and post 31 July irrigations) in Model B. Further, model selection tests (shown in Tables 8 and 9 in Appendix B) are performed across the three types of water users for Model A and Model B using the likelihood ratio tests. These selection tests give rise to Model A1 and Model B1. The five tests for suitability of the frontier model are thus also performed for Model A1 and Model B1 (in Table 5b). In sum, hypothesis tests are conducted for the following four models:

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

Model B: $Y_i = f(X_i : \beta) + \varepsilon$ where X= area, labour, manure, fertilizer, tractors, oxen, irrigationbefore31july, irrigationafter31july, interact and sandyloamy

Model A1: $Y_i = f(X_i : \beta) + \varepsilon$ where X= area by water source type, labour, manure, fertilizer, tractors by water owner type, oxen, irrigation by water owner type, water owner type dummies (Singly-owned =1, 0 otherwise; Jointly-owned=1, 0 otherwise), interact and sandyloamy

Model B1: $Y_i = f(X_i : \beta) + \varepsilon$ where X= area by water owner type, labour, manure, fertilizer, tractors by water owner type, oxen, irrigationbefore31july by water owner type, irrigationafter31july by water owner type, water owner type dummies (Singly-owned =1, 0 otherwise; Jointly-owned=1, 0 otherwise), interact and sandyloamy

Further to the hypothesis tests, final production function estimates and efficiency scores are shown in Tables 6a, 6b and 7 for the four models.

The first hypothesis tests for no inefficiency effects by testing whether H_o: $\gamma = 0$, where the associated variance of the stochastic error term is significantly different from zero. If inefficiency effects are not stochastic then γ will equal zero because the variance of inefficiency is zero[17]. The test results indicate that inefficiency effects are stochastic thus affirming the adoption of the stochastic production function.

In addition to the first test, the second hypothesis, H_o: $\gamma = \delta_o = \delta_3 = 0$, tests the suitability of the stochastic frontier model versus a deterministic model in which the explanatory variables are part of the production function. The rejection of the null hypothesis would therefore recommends the adoption of a traditional mean response function where the determinants are included as part of the production function. Further, the hypothesis of $\delta_0 = \delta_3 = 0$ tests for stochastic effects which otherwise must equal zero as the stochastic model already includes an intercept and the associated input variable (Battese and Coelli, 1995; Madau, 2005). Rejection of the null hypothesis favours the stochastic specification.

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[17] $\gamma = 0$ results either when $\sigma_u^2 \to 0$ or $\sigma_v^2 \to 1$. A zero value for γ indicates white noise

The third hypothesis H_o: $\gamma; \delta_0; \delta_1 = ...\delta_n = 0$ tests the absence of technical inefficiency effects. Rejection of the null hypothesis indicates that output on plots in the sample are below their output-oriented technically efficient frontier. As a variant to the third hypothesis, a fourth test H_o: $\delta_0; \delta_1 = ...\delta_n = 0$ is conducted to assess no constant and farmer specific effects in the error component. The test results reject the null in favour of inclusion of these variables. And finally the fifth hypothesis, H_o: $\delta_1 = ...\delta_5 = 0$ [18] tests the joint significance of the determinants of inefficiency. Rejection of the null indicates that the included explanatory variables jointly influence farm efficiency even though when taken individually some may not be significant.

[18] Alternately, this is also the test for a truncated normal distribution. If the non-intercept terms are jointly not significantly different from zero, then all that remains is the intercept and the non-varying truncated normal distribution.

Table 5(a): Hypothesis tests for the stochastic production function (Model A & B)

Null Hypothesis	LR Statistic (λ)		Critical Values (5%)
	Model A	Model B	
$\gamma = 0$ No inefficiency	11.32	12.08	$\chi^2_{(1))}$ = 2.71 *
$\gamma = \delta_o = \delta_3 = 0$ No stochastic effects	28.26	26.58	$\chi^2_{(3)}$ = 7.05 *
$\gamma = \delta_0 = \delta_1 ... \delta_5 = 0$ Absence of TE effects	40.00	39.38	$\chi^2_{(7)}$ = 13.40 *
$\delta_0; \delta_1 = ... \delta_5 = 0$ No constant & farm specific factors	28.88	27.30	$\chi^2_{(6)}$ = 12.59
$\delta_1 = ... \delta_5 = 0$ Joint significance of determinants	25.62	25.12	$\chi^2_{(5)}$ =11.07

**The statistic λ follows a mixed chi square distribution because the test involves equality and inequality($\gamma > 1$) restriction.. Values are taken from Kodde and Palm (1986)*

Table 5(b): Hypothesis tests for the stochastic production function (Model A1 & B1)

Null Hypothesis	LR Statistic (λ)		Critical Values (5%)
	Model A1	Model B1	
$\gamma = 0$ No inefficiency	9.74	12.53	$\chi^2_{(1))}$ = 2.71 *
$\gamma = \delta_o = \delta_3 = 0$ No stochastic effects	25.46	25.48	$\chi^2_{(3)}$ = 7.05 *
$\gamma = \delta_0 = \delta_1 ... \delta_5 = 0$ Absence of TE effects	32.36	32.36	$\chi^2_{(7)}$ = 13.40 *
$\delta_0; \delta_1 = ... \delta_5 = 0$ No constant & farm specific factors	22.6	19.82	$\chi^2_{(6)}$ = 12.59
$\delta_1 = ... \delta_5 = 0$ Joint significance of determinants	21.42	19.62	$\chi^2_{(5)}$ =11.07

**The statistic λ follows a mixed chi square distribution because the test involves equality and inequality($\gamma > 1$) restriction.. Values are taken from Kodde and Palm (1986)*

Table 6a: Estimates of the stochastic production function and inefficiency effects model for irrigation as a single variable and by types of water users

MODEL A:

Variable	Estimate	S.E
β_0 Constant	3.892	(0.177)*
β_1 Area	0.738	(0.421)*
β_2 Labour	0.0631	(0.027)*
β_3 Manure	0.005	(0.006)
β_4 Fertiliser	-0.032	(0.017)*
β_5 Tractor	0.097	(0.019)*
β_6 Ox	0.100	(0.016)*
β_7 Irrigation	0.059	(0.024)*
β_8 Interact	-0.076	(0.007)*
β_9 Sandyloamy	-0.015	(0.023)
δ_0 Constant	0.393	(0.238)*
δ_1 Education	-0.028	(0.009)*
δ_2 Age	-0.003	(0.003)
δ_3 Area	-0.043	(0.019)*
δ_4 Distance	0.003	(0.0002)**
δ_5 Discharge	0.009	(0.006)**
σ^2	0.073	(0.013)*
γ	0.752	(0.069)*
$\gamma^* = \gamma / \left[\gamma + (1-\gamma)\frac{\pi}{\pi - 2}\right]$	= 0.52	
log likelihood function =		85.19

MODEL A1 :

Variable	Estimate	S.E
β_0 Constant	3.412	(0.218)*
β_1 Area	0.632	(0.064)*
β_2 Area*Singleowner	0.215	(0.099)*
β_3 Area*Jointowner	0.129	(0.068)*
β_4 Labour	0.066	(0.025)*
β_5 Manure	0.004	(0.006)
β_6 Fertiliser	-0.035	(0.017)*
β_7 Tractor	0.133	(0.029)*
β_8 Tractor*Singleowner	-0.026	(0.025)
β_9 Tractor*Jointowner	-0.070	(0.030)*
β_{10} Ox	0.106	(0.154)*
β_{11} Irrigation	0.185	(0.048)*
β_{12} Irrigation*Singleowner	-0.265	(0.088)*
β_{13} Irrigation*Jointowner	-0.135	(0.054)*
β_{14} Singleowner	0.990	(0.308)*
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	0.067	(0.013)*
γ	0.743	(0.073)*
$\gamma^* = \gamma / \left[\gamma + (1-\gamma)\frac{\pi}{\pi - 2}\right]$	= 0.51	
log likelihood function =	93.63	

Figures in brackets are standard error

Table 6b: Estimates of the stochastic production function and inefficiency effects model for pre-and post31july irrigation and by types of water users

MODEL B

Variable	Estimate	S.E
β_0 Constant	3.866	(0.164)*
β_1 Area	0.740	(0.041)*
β_2 Labour	0.062	(0.026)*
β_3 Manure	0.006	(0.006)
β_4 Fertiliser	-0.032	(0.017)*
β_5 Tractor	0.100	(0.018)*
β_6 Ox	0.103	(0.015)*
β_7 Irrigation<31July	0.076	(0.026)*
β_8 Irrigation>31July	-0.007	(0.017)
β_9 Interact	-0.074	(0.007)*
β_{10} Sandyloamy	-0.015	(0.023)
δ_0 Constant	0.253	(0.183)**
δ_1 Education	-0.029	(0.011)*
δ_2 Age	-0.002	(0.003)
δ_3 Area	-0.043	(0.012)*
δ_4 Distance	0.005	(0.0002)*
δ_5 Discharge	0.009	(0.006)**
σ^2	0.083	(0.019)*
γ	0.773	(0.070)*
$\gamma^* = \gamma / \left[\gamma + (1-\gamma)\frac{\pi}{\pi-2}\right]$ =	0.55	
log likelihood function =	87.68	

MODEL B1:

Variable	Estimate	S.E
β_0 Constant	3.523	(0.186)*
β_1 Area	0.657	(0.060)*
β_2 Area*Singleowner	0.103	(0.073)**
β_3 Area*Jointowner	0.100	(0.066)**
β_4 Labour	0.071	(0.025)*
β_5 Manure	0.003	(0.006)
β_6 Fertiliser	-0.030	(0.017)*
β_7 Tractor	0.139	(0.029)*
β_8 Tractor*Singleowner	-0.040	(0.026)**
β_9 Tractor*Jointowner	-0.081	(0.030)*
β_{10} Ox	0.100	(0.015)*
β_{11} Irrigation<31July	0.167	(0.039)*
β_{12} Irrigation<31July*Singleowner	-0.154	(0.061)*
β_{13} Iirrigation<31July*Jointowner	-0.117	(0.049)*
β_{14} Irrigation>31July	-0.007	(0.018)
β_{15} Singleowner	0.535	(0.186)*
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	0.071	(0.014)*
γ	0.768	(0.063)*
$\gamma^* = \gamma / \left[\gamma + (1-\gamma)\frac{\pi}{\pi-2}\right]$ =	0.53	
log likelihood function =	94.73	

Figures in brackets are standard errors

8.2 Production Estimates

The parameter estimates for Model A and Model B indicate that with the exception of fertiliser all the input variables indicate a positive relationship with output. Manure is not significant and field observations show that manure was an unsold commodity that was applied by farmers as a residual input. In the village, manure had a competing use for cooking fuel. A plausible explanation for the low but significant negative elasticity of fertiliser costs is derived from the delay in the monsoon rains which arrived in August instead of July. This affected not only the timing and frequency of waterings due to poor and erratic power supply but also the interaction of water, which is 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 is not surprising as most plots recorded a tapering off of irrigations with the arrival of the monsoons. Further, the summer months coincide with the growing period for the sugar cane crop and are crucial to plant growth, which explains the significant and positive relationship for irrigation prior to 31 July. The negative elasticity on the interaction of labour with crop dummy indicates that labour for fresh-sown (non-rattoon) sugar cane reduces output by 7% for every hourly increase in labour. 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 in the surveyed village used labour more intensively for the fresh sown crop, requiring more attention than for the existing rattoon crop, and tended to overcompensate for labour use which suffered from its own peculiarities arising from the migrant labour force, making it less of a pre-determined input after irrigation.

The model selection test reveals a difference in slopes for select input variables: land area and tractors–strong correlates of wealth, and irrigation–arising from differential access to water. Sugar cane cultivation is a labour intensive activity. The use of tractors is limited to land preparation and 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 it 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 labour). Further, the data collected revealed that tractors and oxen were in fact substitutes. Tractor usage was not popular, with only half the plots reporting its use, whereas more than

90 percent of the plots used oxen, suggesting that tractors are potentially a status symbol. This is also mitigated by the availability of cheap labour.

The negative elasticity of irrigation before 31 July[19] for single and joint tubewell owners' plots may appear counterintuitive but given the nature of irrigations that are highly dependant on electricity supply, it is not surprising that single and joint owners had a tendency to over - irrigate their fields. These plots were the most fortunate in terms of water volumes received on account of greater control and access in the crucial growing period of sugar cane in the summer months. Field observations indicate that farmers' control was heavily constrained by electricity shortages and often unpredictable supply. This led to a "run on the pumps" with farmers running their pump sets for several days during intermittent supply until their fields were fully flooded (i.e. until standing water). This finding is supported by survey data analysis in Table 2, where the distribution of water over the first few irrigations shows that single and joint owners had greater access in terms of percentage of their plots irrigated before 31 July and the average gap between irrigations was lower as compared to buyer's plots.

8.3 Technical Efficiency

In this paper an output-oriented measure of technical inefficiency is employed and is defined as the maximum output obtainable from inputs. It is described by the production relation Y = f(X). TE where TE is a measure of the deviation of current output from its possible maximum. Thus $TE_{output} \leq 1$ with TE = 1 capturing zero inefficiency. For TE <1, (1- TE) is the percentage increase possible in output. Thus, technical efficiency is understood as the ability of a firm to increase its output to the maximum possible level without a corresponding increase in input use. Technical efficiency can be viewed as redistribution of the current resources in a way that maximizes production.

Technical efficiency estimates are presented in Table 7. The average output-oriented efficiency score for all farmers is 0.85 across all the models considered which implies that on average the output produced is 85% of the best practice frontier output. Hence, an average TE score of 0.85 implies that output on all plots taken together for all three categories of water

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

users can be increased by 15% through a more effective use of their input bundle given their present state of technology. Mean values per bigha of land for the three categories of farmers are shown in Table 11 in Appendix C.

The structure of production is captured by an analysis of γ and the parameter estimates of the Z_i covariates (in tables 6a and 6b). The variance parameter γ is significant across all models and thus technical efficiency is significant in explaining output variability amongst our farmers[20]. However, Coelli T.J (1995), Coelli et al, (1998), Kumbhakar and Lovell (2000) show that the relative contribution of the inefficiency effects to the total variance is given by $\gamma^* = \gamma / \left[\gamma + (1-\gamma)\frac{\pi}{\pi - 2} \right]$ because the variance of u_i equals $[(\pi\text{-}2)/\ \pi]\sigma_u^2$[21] and not σ_u^2[22].

Hence γ is not an exact representation of the ratio of the variance of u_i to the variance of the composed error. Recalculating for γ^* reveals that a little more than half (between 51% to 55%) of the differential between observed and best practice output arises from the existing difference in efficiency across our set of farmers.

Technical efficiency scores for the three types of water users in Table 7 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 irrigation source to assess whether the difference in TE scores was significant. The test results shown in Table 7 indicate that the estimated TE scores were significantly different amongst the three types of water users and is thus attributable to the input mix adopted by the three types of farmers. An example of the distribution by percentage of farmers and by water type in the hierarchy of TE

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

[21] A formal derivation for the variance of u_i for the truncated (at zero) normal case can be found in Stevenson (1980), p. 60

[22] γ^* is derived by substituting everywhere $[(\pi - 2)/\pi]\sigma_u^2$ and by using $\sigma_u^2 = \sigma^2 \gamma$ and $\sigma_u^2 = (1-\gamma)\sigma^2$ in equation 8 in the expression for γ

Table 7: 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 ownes and Buyers**:** t = 3.5063 ; P > |t| = 0.0006

ModelA1	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

scores is shown in Appendix C for Model A. It can be seen that for owner plots most of the generated efficiency scores fall in the highest range but for plots serviced by water purchasing agreements and by shared water sources, there is a shift with the largest bulk of the scores falling in the second highest (from 0.80-0.90) range.

Further investigation of TE scores reveals that on average, owner plots could increase output by 11%, joint owner plots could potentially increase output by 15% and buyer plots could witness a 20% increase in output. In terms of income gains, such potential increases in output across the three types of farmers translate for owners' plots to Rs.649 per bigha, for joint owners' plots to Rs. 889 for buyers' plots and Rs. 1082 per bigha. Hence, the greatest income gains accrue to the most water rationed category of farmers followed by the next water rationed category of plots served by jointly owned tubewells. Thus income gains follow an inverse relationship to access to water with income gains increasing with improved control over water for crop production. For all farmers' plots as a whole, income gains averaged Rs. 867 per bigha.

With respect to the determinants of inefficiency, Tables 6a and 6b show that all five variables when taken together are significant for sugar cane production even though individually some may not be. A negative sign on the determinant variables implies an increase in technical efficiency whereas a positive sign shows the reverse[23]. 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 discharge, the latter possibly arising from wastage and standing water in the fields. In sum, returns to education are positive while an increase in land area suggest scale economies. A larger distance between irrigation source and farmers plots is explained both by the time taken to reach the plot and by losses from seepage as all channels were unlined and were made of mud banks. However the effect is weak as many of the irrigated plots were contiguous to each other. In addition, 73% of all plots were within 100 meters of the irrigation source (average for all farmers was 107 meters).

[23] Note: U measures the deviation of observed output to best practice output and is thus a measure of inefficiency.

9. Conclusions and Policy Implications

This paper uses the stochastic frontier production function to estimate technical efficiency scores amongst a cross section of sugar cane growing farms in the western belt of Uttar Pradesh. The results of the study indicate the presence of technical inefficiency, which captures between 51% to 55% of the differential between observed and best practice output. The presence of inefficiency implies that through a redistribution of the current input bundle, farmers can improve their sugar cane production. Further, plots serviced by owner's tubewells ranked the highest in terms of efficiency scores followed by plots serviced by jointly held tubewells. Buyer's plots, relative to the other two categories ranked the lowest.

Frontier production estimates reveal that irrigation when used as single input variable (Model A) notes a positive contribution to sugar cane production, but when split by timing into pre- and post-31july irrigations (Model B) reveals that water in the summer months is crucial when the crop is young and in its growing phase and in need of vital water inputs. Estimation results on further disaggregation of the production function by water type (Model A1 and Model B1) indicate that amongst the three categories of water users, water is being indiscriminately used on plots serviced by single and joint owner tubewell and were being overcompensated for the lack of water. This misallocation as it were is brought about by the uncertainty in the electricity schedule, electricity being the source of power for pumpsets that power the tubewells. Consequently, farmers with their own tubewell owners (single and joint categories) are almost always running their tubewells in the summer to ensure against future uncertainties to overcome the stochastic nature of water inputs to the extent possible.

With respect to income gains for the three category of plots, the largest gains accrued to the most water rationed plots, followed by the next category of joint water plots suggesting that water ownership disproportionately favours owners and are highly inequitable. This occurs despite in-optimal use of inputs on plots serviced by their own tubewells.

In the surveyed village as in the rest of the sugar cane growing belt, the lack of alternate and reliable sources of irrigation and limited or no access to canal water or publicly provided tubewell water have driven the farmers to invest in tubewell technology to insure against uncertainties in the weather (namely delays in the monsoon showers) and rigidities in distribution of canal water. Further, the growth of lucrative crops such as the water thirsty sugar cane by farmers also demands timely application of inputs that are to a large extent conditioned by availability of water at the appropriate times. Tubewell technology requires lumpy investments and is conducive to taking place on larger plots and by wealthy farmers. In a situation of declining water tables, tubewell installation costs have been steadily increasing. Further, well failure was also observed where a previously dug well had to be abandoned as the water level had dropped. Despite these obstacles, farmers have been increasingly investing in their own water extraction devices.

The determinants of inefficiency reveal that land fragmentation is an obstacle to efficiency as water must be transported over long distances. Fragmentation of land often takes place where a plot of land was divided amongst sons and was not unique to the surveyed village. The spatial spread of plots in different locations (or directions) coupled with high tubewell investment costs meant that farmers invested in tubewell technology on relatively larger plots and bought water from nearby plots with tubewells for the remaining smaller and scattered plots. Transactions were conducted at a centrally-determined village-wide price greatly in excess of cost of extraction, thus bearing little correlation with the latter. The lining of channels was not observed largely due to the associated material and labour costs. Hence, each tubewell served a limited number of neighbouring plots and is akin to the natural monopoly paradigm. However, while fragmentation of land worked against efficiency, on the other hand it favoured a more egalitarian distribution than would have otherwise been had land consolidation been complete and regular. In the surveyed village, the disparate location of plots meant that owners of tubewells were buyers for their other plots with no tubewells. This was coupled with the fact that a centrally-determined village level price implied a 'moral' economy where sellers could not unilaterally change the water tariffs without being black listed and most importantly could not ignore the repercussions on themselves on plots where they were buyers. Thus the spatial spread of plots provided for a more conductive environment to equitable exchange

The lack of transportation systems such as pipes ordinarily would reinforce the monopoly effects of tubewell owners. On the contrary, the findings show that such monopoly effects can be mitigated by the density of tubewells, social norms and multiple exchanges between farmers with the roles of owner and buyer being interchanged. In the case of joint owners, the tubewell served the plots of the partners following a rotational schedule in priority of investments made. Hence, farmers with the highest investments received water first followed by the next highest investor. Different partnerships were formed on different plots that were not contiguous to each other, thereby self-enforcing contracts and ensuring them against reneging of agreements. Hence, the exchange of water buttressed by social norms mitigates against the operation of monopoly powers, and provides for a more equitable distribution of water than would have been without such practices.

The timing of water is crucial in the summer months especially for the young sugar cane crop. And it is in these months that electricity supply is most erratic and of a lesser duration. In the pre-monsoon months, electricity supply averaged 5-6 hours in May, 8-10 hours in June and then decreased to 2-3 hours in July. During these three months there was no rainfall. The monsoons arrived late in the survey year in the last week of July / first week of August, further exacerbating the power supply situation. Although there exists an electricity schedule with day and night weekly rotations, the electricity supplied is frequently of low voltage and is discontinuous and erratic with several power cuts, further adding to the constraint to water supply. This constraint is felt the most by water buyers as they receive only water in surplus to the needs of the sellers. With fluctuations in the electricity supply, sellers frequently renege on their dates of delivery, evidenced by the longer gaps between irrigations on bought water plots.

While the farmers are quick to blame the State Electricity Board for the water situation, they only pay a flat rate for electricity charged on a monthly basis and billed annually or semi-annually. There are no meters attached to the pumpsets and charges are based on per unit horsepower of the pumpset. Often farmers pay their bills late and can be exempt from the late fees[24]. Further, the flat tariffs charged for power are based on *reported* horsepower of pumps and not *observed* horsepower and there exists a disparity between the two. The motivation to underreport is to reduce the burden of payment for electricity as farmers are unsatisfied with the quality of power they receive. Hence, the situation is one where the farmers blame the state for unreliable power and the state receives little in terms of dues and revenues and the cycle continues. Farmers will have to be assured of the quality of their power supply and for its promised duration to motivate them to pay their fair electricity dues, which in turn will generate revenues for the power houses providing them incentive to supply good quality

[24] On one of the field trips, an announcement was made where farmers were being encouraged to submit their electricity payments by waiving their late fees.

power. This in turn will have a positive impact on the distribution of water between water owners and buyers are will reduce existing disparities in efficiency, production and income. The farmers' responses to their particular environment has been to acquire more and more control over water and thereby to have greater control over the production process to augment output and yields on their plot, to insure themselves against the vagaries of the weather, and to reduce their dependency either on the state[25] or water sellers. TE estimates across the three types of plots show that (1) water markets disproportionately favour tubewell owners over buyer's plots, but this to a certain extent is undermined by the spatial distribution of plots; (2) a shift towards joint ownership of tubewells should be encouraged to reduce the extreme disparity amongst water buyers' and water owners' plots and to work towards not only a more equitable distribution of water but overall towards more efficient production. This move towards partnership is encouraged given the lumpiness of investment and continuing fragmentation of land. An examination of the working conditions reveals that (3) misallocation of water resources on plots serviced by tubewells can be overcome by regulating electricity supply. Finally, the operating environment in the village reveals that (4) 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.

Sources of inefficiency show that the (5) education of the farmer is imperative in reducing technical inefficiency. Hence, training should be provided to farmers on best practice techniques that incorporate application and / or use of other inputs common in the production process. Although a weak effect, (6) 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.

Farmers will continue to invest in tubewell technology rather than to rely on water markets in an environment where inequities in output and in water delivery exist between water types. Water exchanges in an environment where farmers feel obliged to supply water (motivated either by a tacit moral economy or their own needs on their non-serviced plots) ameliorates to a certain extent the disparity in a water-rationed world, but does not stop farmers from

[25] Although there were government tubewells in the village, they numbered only two and farmers were reluctant to use them as they had to await their turn as part of a rotation cycle.

investing in tubewell technology and contributing to the declining 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.

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Appendix A

For plots with one variety of sugar cane the average yield was calculated by using the plot area. For plots with both varieties or mixed plots, area allotted to each type had to be constructed. A ratio "a" of the average yields across the early and general variety was computed .

For a "mixed plot" *t*, let E_t, G_t, A_t, X_t be, respectively, output of early and general varieties, total plot area, and area under early variety. This last variable was unobserved. We assumed that the early and general yields were in the proportion *a* computed above. Using this ratio, we applied the following :

$(E_t / X_t) = a(G_t /(A_t - X_t))$, from which we obtained

$X_t = A_t E_t /(aG_t + E_t)$.

Having calculated X_t, we then computed the two yields from this plot as,

$(E_t / X_t),(G_t /(A_t - X_t))$.

Yields for each plot were then calculated using an average across the two varieties for mixed plots

Appendix B

Model Selection Tests

Unrestricted model:

$$\text{LogY} = \beta_0 + \beta_1 Area + \beta_{11} LogArea * SingleOwner + \beta_{12} LogArea * JointOwner$$
$$+ \beta_2 LogLabour + \beta_{21} LogLabour * SingleOwner + \beta_{22} LogLabour * JointOwner$$
$$+ \beta_3 LogManure + \beta_{31} LogManure * SingleOwner + \beta_{32} LogManure * JointOwner$$
$$+ \beta_4 LogFertiliser + \beta_{41} LogFertiliser * SingleOwner + \beta_{42} LogFertiliser * JointOwner$$
$$+ \beta_5 LogTractor + \beta_{51} LogTractor * SingleOwner + \beta_{52} LogTractor * JointOwner$$
$$+ \beta_6 LogOxen + \beta_{61} LogOxen * SingleOwner + \beta_{62} LogOxen * JointOwner$$
$$+ \beta_7 LogIrrigation + \beta_{71} LogIrrigation * SingleOwner + \beta_{72} LogIrrigation * JointOwner$$
$$+ \beta_8 Interact + \beta_9 Sandyloamydum + \beta_{10} SingleOwner + \beta_{13} JointOwner$$

Table 8: Tests of hypothesis: Model A1

Null Hypothesis	LogLikelihood	λ	Outcome
H_1: Unrestricted model	89.80		
Ho: $\beta_{10} = \beta_{13} = 0$ Water Type Intercepts	83.60	12.4*	Reject
Ho: $\beta_{10} = \beta_{11} = 0$ Area slopes	85.93	7.74*	Reject
Ho: $\beta_{21} = \beta_{22} = 0$ Labour slopes	88.92	1.76	Fail to Reject
Ho: $\beta_{31} = \beta_{32} = 0$ Manure slopes	87.74	4.12	Fail to Reject
Ho: $\beta_{41} = \beta_{42} = 0$ Fertiliser slopes	89.62	0.36	Fail to Reject
Ho: $\beta_{51} = \beta_{52} = 0$ Tractor slopes	84.02	11.56*	Reject
Ho: $\beta_{61} = \beta_{62} = 0$ Ox slopes	86.85	5.90	Fail to Reject
Ho: $\beta_{71} = \beta_{72} = 0$ Irrigation slopes	85.62	8.54*	Reject

* indicates significance at the 5% level, $\chi^2_{(0.95)}$ =5.99

Model Selection Tests

Unrestricted model:

LogY= $\beta_0 + \beta_1 Area + \beta_{11} LogArea * SingleOwner + \beta_{12} LogArea * Jo\text{int}Owner$

$+ \beta_2 LogLabour + \beta_{21} LogLabour * SingleOwner + \beta_{22} LogLabour * Jo\text{int}Owner$

$+ \beta_3 LogManure + \beta_{31} LogManure * SingleOwner + \beta_{32} LogManure * Jo\text{int}Owner$

$+ \beta_4 LogFertiliser + \beta_{41} LogFertiliser * SingleOwner + \beta_{42} LogFertiliser * Jo\text{int}Owner$

$+ \beta_5 LogTractor + \beta_{51} LogTractor * SingleOwner + \beta_{52} LogTractor * Jo\text{int}Owner$

$+ \beta_6 LogOxen + \beta_{61} LogOxen * SingleOwner + \beta_{62} LogOxen * Jo\text{int}Owner$

$+ \beta_7 LogIrrigationbefore31july + \beta_{71} LogIrrigationbefore31july * SingleOwner$

$+ \beta_{72} LogIrrigationbefore31july * Jo\text{int}Owner$

$+ \beta_8 LogIrrigationafter31july + \beta_{81} LogIrrigationafter31july * SingleOwner$

$+ \beta_{82} LogIrriafter31july * Jo\text{int}Owner$

$+ \beta_9 Interact + \beta_{10} SandyloamyDum + \beta_{13} SingleOwner + \beta_{14} Jo\text{int}Owner$

Table 9: Tests of hypothesis: Model B1

Null Hypothesis	LogLikelihood	λ	Outcome
H_1: Unrestricted Model	95.12		
Ho: $\beta_{13} = \beta_{14} = 0$ Water Type Intercepts	87.60	15.04*	Reject
Ho: $\beta_{11} = \beta_{12} = 0$ Area slopes	90.90	8.44*	Reject
Ho: $\beta_{21} = \beta_{22} = 0$ Labour slopes	93.89	2.46	Fail to reject
Ho: $\beta_{31} = \beta_{32} = 0$ Manure slopes	93.42	3.4	Fail to reject
Ho: $\beta_{41} = \beta_{42} = 0$ Fertiliser slopes	94.75	0.74	Fail to reject
Ho: $\beta_{52} = \beta_{52} = 0$ Tractor slopes	90.24	9.76*	Reject
Ho: $\beta_{13} = \beta_{14} = 0$ Ox slopes	92.17	5.90	Fail to Reject
Ho: $\beta_{71} = \beta_{72} = 0$ Irrigationbefore31july slopes	92.11	6.02*	Reject
Ho: $\beta_{81} = \beta_{82} = 0$ Irrigationafter31july slopes	94.39	1.46	Fail to Reject

* indicates significance at the 5% level, $\chi^2_{(0.95)}$ =5.99

Appendix C:

Table 10: Distribution of technical efficiency scores by farmers and their water type (Model A)

All Farmers' Plots

Range	Frequency	Distribution (%)
<0.30	0	0
0.30-0.40	1	0.3
0.40-0.50	1	0.3
0.50-0.60	11	3.37
0.60-0.70	20	6.13
0.70-0.80	41	12.57
0.80-0.90	130	39.88
0.90-1	122	37.42

Range	**Single Owners' Plots** Distribution (%)	**Joint Owners' Plots** Distribution (%)	**Buyers' Plots** Distribution (%)
<0.30	0	0	0
0.30-0.40	0	0	1.36
0.40-0.50	0.87	0	0
0.50-0.60	0	1.63	10.23
0.60-0.70	2.61	7.32	9.09
0.70-0.80	7.83	14.64	15.9
0.80-0.90	29.57	47.15	43.18
0.90-1	59.13	29.27	20.45

Table 11: Mean Values per bigha at the plot level by water user

	Single Owners' Plots	Joint Owners' Plots	Buyers' Plots
Yields	58.05 (15.41)	58.17 (16.55)	53.691 (15.74)
Labour	171.94 (78.18)	185.34 (78.40)	194.01 (118.75)
Manure	19.40 (25.45)	16.04 (21.63)	18.60 (28.70)
Fertiliser	234.53 (118.07)	232.87 (177.67)	233.60 (130.51)
Tractor	1.62 (2.65)	.64 (1.63)	.77 (1.31)
Ox	10.88 (6.86)	11.96 (6.25)	10.91 (7.46)
Irrigation	32.08 (6.66)	29.03 (10.60)	22.34 (7.76)
Irrigationbefore31july	14.98 (5.69)	13.43 (6.26)	10.98 (4.74)
Irrigationafter31july	17.09 (4.81)	15.60 (7.04)	11.35 (5.72)

Figures in brackets are standard deviations