Groundwater Irrigation in North India: Institutions and Markets

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Abstract

This paper analyzes the institutions and markets that govern groundwater allocation in the sugarcane belt of Uttar Pradesh, India, using primary, plot-level data from a village which shares the typical features of this region. Electricity powers tubewell pumps, and its erratic supply translates into randomness in irrigation volumes. The paper finds that plots are water-rationed, owing to inadequate supply of power. A simple model shows that a combination of such rationing and the village-level mechanism of water sales can lead to great misallocation of water across plots, and result in large crop losses for plots that irrigate using purchased water. We infer the existence of a social contract that mitigates these potential losses in the study area to a remarkable extent; in its absence, average yields are estimated to be 18% lower. The finding that the water allocation is close to efficient (given the power supply) marks a sharp contrast with much of the existing literature. Notwithstanding the social contract, the random and inadequate supply of power, and therefore water, is inefficient. The dysfunctional power supply is part of a larger system of poor incentives to produce reliable and adequate power. In simulations we find that such reliability can improve yields by up to 10 %, and pay for a system of electricity pricing that gives incentives to the power supplier to actually provide adequate power. However, even at reasonably high power prices, irrigation volumes are large enough to continue to seriously deplete the water table. The problem is that traditional rights of water use do not take into account the shadow price of the groundwater. We provide a rough first analysis to suggest that a 15% markup on the economic unit cost of providing electricity would make for intertemporally efficient water use.

Key words: Water markets, water tables, water production function, water pricing.

GROUNDWATER IRRIGATION IN NORTH INDIA: INSTITUTIONS AND MARKETS

A.Banerji, Gauri Khanna and J.V. Meenakshi

1. Introduction

Amidst rapidly growing economic activity in India, there are increasing concerns of water scarcity. Eighty five percent of all water use in the country occurs in rural India, most of it in the form of groundwater irrigation. In North India, the popularity of water intensive crops (paddy, sugarcane) is said to be responsible for decreasing groundwater tables. This raises concerns about the overexploitation of groundwater resources, and the consequent sustainability of agriculture in this region. In this context, it is important to ensure that the quantum of groundwater that is used for irrigation yields the maximum possible crop output.

This paper is based on a primary survey conducted in village Tabelagarhi, located in the sugarcane belt in Western Uttar Pradesh, India, that was collected to address this concern. We study the institutions that govern water allocation in order to (i) find out and quantify how well or poorly they perform with respect to water-allocative efficiency and intensity of water use, (ii) analyze their performance in terms of a simple stylized model that can explain observed water allocation outcomes, and (iii) suggest the kinds of changes necessary to improve water use in terms of efficiency and sustainability.

The broad sugarcane belt has a water economy that shares the institutional features observed in Tabelagarhi. These include predominant or exclusive use of groundwater for irrigation, and a low and declining water table that makes it uneconomical to use diesel to fuel the pumps that run the tubewells. The pumps thus use electricity to draw water from depths of 70 feet and below. Another common feature in the region is the erratic and inadequate electricity supply from the State; this randomness in power supply translates, therefore, to randomness in the supply of irrigation water. Fragmented landholdings and wide variation in plot sizes imply that many plots, particularly smaller ones, do not have tubewells. With declining water tables, submersible pumps are increasingly preferred to non-submersibles, but these are expensive to install[1]; this tends to accentuate the fact that smaller plots go without tubewells, even though the region itself has high tubewell density. As a result, a lot of plots are irrigated using purchased water from informal water markets.

We address the question of allocative efficiency of groundwater by estimating a sugarcane production function for our surveyed village, Tabelagarhi, using plot-level data on inputs and sugarcane output. From this, and the observed input levels for each plot, we estimate the marginal productivity of water (MPW) across plots and find that this varies significantly, providing evidence of some misallocation of water. However, a simulation shows that the gains from reallocation are very small if we redistribute the

[1] The difference in the volume of water per unit time pumped up favors submersibles, and increases with water depth. Submersible pumps cost upwards of Rs. 150,000.

observed volume of water that each tubewell discharges over the season to the plots that it services.[2]

That water allocation is close to efficient in this static sense is a striking result, and stands in sharp contrast to much of the literature on South Asia. Many studies have argued that tubewell owners exercise some monopoly power over water buyers, leading to inefficient water allocation and inequitable outcomes. However, the extent of inefficiency has never been quantified; a basic requirement for such quantification is to measure irrigation volumes, which is not done in most studies. As a consequence, conclusions about large inefficiencies have sometimes needed an element of faith.

We also investigate whether inadequate power supply leads to plots being water-rationed. To do so, we compare the marginal value product of water on a plot with its water price (if the plot uses purchased water) or the marginal cost of water extraction (if the plot has a tubewell on it); we find that the marginal value product exceeds the water price/ marginal cost on almost all plots; on average across all plots, the marginal value product is 2 ½ times the water price. This is evidence of significant water rationing.

As indicated earlier, much of the literature on water markets implicitly or explicitly treats tubewells from which water is sold as water-producing firms, and explains inefficiency in terms of their having some monopoly power.[3] It is argued that monopoly power is higher if there is low tubewell density and if unlined water channels 'compel' farmers to purchase from the nearest tubewell. We find that such models are not directly applicable either to Tabelagarhi or indeed to the region as a whole. For one thing, a uniform water price *per hour* of tubewell use is set in an informal village-level agreement at the beginning of the season, and is adhered to in water transactions; so water sellers can only adjust the *quantity* of water sales.[4] Moreover, the price does not vary across the season in response to varying power (and therefore water) availability, to clear the market.[5] Most importantly, tubewell owners who sell water do not choose water sales to maximize profits, in the ordinary sense of the term.

These features necessitate a departure from the framework typically used in the literature. Instead, we construct a simple model that captures the institutional characteristics that govern water transactions in this region. While details of the model are set out in subsequent sections, we provide here a brief preview, and the kinds of

2 Restricting the reallocation from a tubewell to the plots that it services is reasonable in our context because these plots are located near the tubewell. Transporting water to distant plots over the existing, unlined water channels would result in large seepage losses.

3 See for example Shah (1993), Meinzen-Dick (1996) and Jacoby, Murgai and Rehman (2004).

4 Volumes of water discharged per unit time vary considerably across tubewells; they are significantly lower for non-submersibles. So a uniform per hour water price translates into tubewell-specific water prices *per unit volume* of water. We calculate these prices using the measured discharge rate of each tubewell.

5 Note also that even though the tubewells in our study area sell water mostly to nearby plots (to prevent seepage losses from unlined water channels), there is no evidence of monopoly power in terms of price-cost margins. The village-level water price per hour is insignificantly different from the mean average cost of water extraction in the village.

questions we are able to analyze using it. In Tabelagarhi as elsewhere in the region, water sellers are primarily cultivators who sell "surplus water" (i.e. surplus to the requirements of their own plots). The analysis shows that farmers sell substantial volumes of water even though the value of the marginal product of water (MPW) on their own plots is much larger than the water price. In such a situation, maximizing profits would instead have implied that the tubewell owner uses all the water on his own plots, until the values of MPW on those equaled the water price; and sell water only after that point. The observed water allocation implies therefore that water sales or sharing are driven by *social norms or a social contract*. Such a social contract is not necessarily coercive. Owing to fragmented holdings, practically all water sellers also have plots that buy water from elsewhere. What a water seller loses by selling water at a price lower than its value on his own plot, he can make up by getting water on those of his plots that are serviced by others' tubewells.

The modeling of the social contract helps to formalize this argument and highlight its role in ensuring a close to efficient water allocation. A simulation exercise shows that yields would be about 18% lower if tubewell owners' quantities of water sales were chosen to maximize individual profits in the conventional sense, at the observed village-level water price. The model also helps to emphasize that if such a social contract is in place, inferring about allocative efficiency on the basis of price-cost margins (as is done frequently) can be very misleading.

That farmers, in the face of water rationing, have worked out a water allocation reasonably close to being efficient may be a consequence of the relative social homogeneity of Tabelagarhi and surrounding villages. We argue in the paper that erratic and inadequate power nevertheless extracts a toll; we quantify efficiency gains from power supply reform. Many key decisions on input applications (including fertilizer applications) for land preparation, planting, etc. are done in the first few summer months, whereas irrigation takes place over the entire season/cycle. Therefore, substantive input choices are made in this region *before* farmers get to know how the power availability will affect irrigation over the season. In simulations that assume reliable and adequate power and therefore water, we show that yields go up by more than 9% on average, relative to sample yields.[6] Higher yields are explained by a combination of increased irrigation volumes in the absence of power shortages, and increased use of complementary inputs at given irrigation volumes, by risk-averse farmers, when reliable power supply removes the uncertainty in irrigation water.

The rationing of water that our analysis finds is not meant to economize on a scarce resource. Rather, it is a consequence of the pan-Indian problem of poor power infrastructure, and poor incentives to produce and supply power. Poor incentives are

6 In addition, proper *timing* of irrigations is crucial for sugarcane plant growth; random and inadequate power compromises this as well. But our aggregative analysis cannot quantify the amount of damage that is attributable to lack of timely irrigations. In a study on Indian data encompassing irrigated and rain-fed areas, Evenson, Pray and Rosegrant (1999) find that irrigation has a positive effect on total factor productivity over and above the value of the water input itself; they attribute this to the ability to time the watering of crops in irrigated (as opposed to rain-fed) areas.

especially the case in agriculture; in most cases, as in Tabelagarhi, farmers pay a flat annual charge (based on the horsepower of their pumps) in return for the right to use as much power as they require. Of course, this gives no incentive to the power provider (here, the State Electricity Board (SEB)) to provide adequate power.[7] Remunerative power prices that are based on the quantum of use would presumably provide enough incentive to a power supplier to supply adequate, reliable power. Our simulations that presume reliable power supply are done in an alternative setting of unit-pricing of power. We show that yield gains are sufficient to pay for the higher cost of power, at reasonable unit prices.

We also study the effect of these alternative scenarios on the all important question of overall water use.[8] We find that at per-unit power prices that cover the economic costs of generating it, irrigation volumes are 6% to 12.5% greater than in the sample. This is understandable, as the profitability of the crop makes it profitable also to expand water use at the margin. While water use can be reduced in the simulation by charging higher power prices still, this may not be feasible for a variety of reasons.[9] Policy must ultimately grapple with the fact that the water used itself has a shadow price, which the water users may not be taking into account. Farmers have traditional rights to groundwater beneath their land, and don't pay to use it. To properly address issues of intertemporal efficiency and sustainability of water use requires more data and detailed knowledge of the region's groundwater hydrology; nevertheless, we make a first attempt at estimating a markup on the power price that would make water use intertemporally efficient.

Although this paper is a village study, it has potentially large implications for North Indian agriculture, because of the common institutional features mentioned above that prevail over a wide swath of agricultural land. To reiterate, these include the cultivation of similar water intensive crops, water transport through unlined channels, informal water markets, and water sharing and pricing norms set at the village level (rather than by individual tubewell owners), as well as similar electricity policies of states.

The rest of the paper is organized as follows. The next section reviews some of the related literature. Section 3 describes the study area and the data. Section 4 proposes a simple model to understand the water economy of the village, and outlines the estimation and simulation methods, with technical details relegated to Appendix B. Section 5 discusses the estimation and simulation results, ending with a short discussion of sustainability. Section 6 concludes with policy recommendations.

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7 There are other systemic problems with the power sector which result not just in poor distribution of power to agriculture, but to poor power generation more generally, across the country and across sectors

8 Efficient allocation of water across space is of course not sufficient for efficiency, as it ignores allocation over time. In the study area, for example, aggregate water use may signify overexploitation relative to a suitably defined golden rule. While the study does not look at this intertemporal aspect directly, the policy simulation helps make inferences about how responsive overall water use may be to policy changes.

9 prices that are acceptable on highly fertile soils (as in the villages in the study area) may be less so on land where yields and farmers' profits are lower.

2. Related Literature

There is a vast literature studying the problems of groundwater, and on water markets, in India. We summarize below some select contributions.[10]

Among the pioneering contributions to the analysis of groundwater markets in India is that of Tushaar Shah (1993). In a comprehensive, pan Indian analysis, his is perhaps the first study to document the various institutional mechanisms through which water sales are transacted. These vary from kind transactions, water contracts interlinked with those for land and/or other inputs, and cash transactions both on a per acre and per volume basis. He observes that while such multiplicity of contract types characterize water markets everywhere, the more 'developed' water markets, such as those found in Northern India, typically rely on prices that depend on volume, and lease contracts, which follow standardized formats. And because of ubiquitous opportunities to buy water, farmers not owning a water extraction mechanism are not necessarily disadvantaged. He also points out that the use of unlined channels to transport water to buyers' fields results in seepage losses as high as 30 to 40 percent. This implies that buyers at some distance from the owner' tubewell face effectively a higher price; another (related) implication is that tubewell owners may act as localized monopolies.

Dubash's (2002) analysis of water markets in Gujarat also documents the co-existence of a multiplicity of contracts used for groundwater sales. The type of contract—whether based on a fixed payment per acre, a price per hour, or a share of the crop—varies across villages and even across crops. Dubash's analysis is unique in at least two respects; first, he effectively captures the dynamic nature of water contracts, which have changed substantially over time. For instance, in one village, he documents a shift away from share payments to fixed payments, largely in response to enforcement difficulties faced by owners, with buyers cheating on the size of the total harvest. Sellers were able to change the terms of the contract 'unilaterally' by exercise of social power; for well owners were typically the large landowners in the village. This had adverse consequences for the reliability of water supplies, which the earlier share system helped ensure. A second significant feature of this study is the salience given to the institutional basis for water contracts. Dubash's analysis highlights the role of social norms in negotiating water contracts; he suggests, for example, that a 'moral' economy operates to prevent sellers from setting anything substantially more than a commonly perceived 'fair' price.

Works that study questions of monopoly power and its attendant inequities, and natural oligopolies in the context of water sales include Shah (1993), Palmer-Jones (1994), Meinzen-Dick (2000), Sengupta (2000) and Dubash (2002). Examining the case of Pakistan, Meinzen-Dick finds that more than half of the water purchasers did not get their water when requested. Analyzing the determinants of reliable supply, she finds

[10] Schoengold and Zilberman (2005) is an excellent general reference on the economics of water use in irrigation. On India, Dhawan's (1995) early work on groundwater irrigation distinguishes degradation arising out of mining of water, the case considered here, from that arising out of increasing salinity. His was the first nuanced study that explicitly addressed crop- and regional- specificities in groundwater systems.

evidence of better service for older and larger landowners and from diesel driven tubewells. Since a switch in technology is expensive (or infeasible) joint ownership of tubewells for medium-sized farmers may be a solution to reducing the disparity between water purchasers and sellers. The study reiterates Shah's finding that water markets do provide small and poor farmers with an alternative but that the benefits disproportionately favor tubewell owners who only provide water when they do not need it themselves.

Jacoby, Murgai and Rehman (2004) examine the extent of monopoly power exercised by tubewell owners, and whether they price-discriminate in favour of their tenants, in Punjab, Pakistan. The framework of analysis used is based on the theory of interlinked contracts, which also predicts that owners of tubewells would use more groundwater relative to those who buy from them. Their results find evidence of price discrimination, which is not explained by either spatial characteristics, or any premium arising out of systematic differences in willingness to pay for 'reliable' water supplies. They also find that tubewell owners and their tenants use significantly more groundwater than buyers of groundwater; the combined evidence thus points to misallocation of groundwater resources in this region as a result of monopoly power. A distinctive feature of this paper is that groundwater transactions are treated in an integrated manner with a parallel 'informal market' in canal water that is commonly observed in their study area. Canal water is allocated by turns, and the market operates by the exchange of turns amongst farmers. The main implication of such trading in canal water is that overall water use (including both ground and canal water) may not be allocatively inefficient as indicated by the analysis of groundwater alone.

Pant (2004) traces the evolution of water markets in eastern and western Uttar Pradesh. His work is 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 Tabelagarhi. 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 maximize yield. Pant concludes that growth increased the demand for power, which while available in plenty in the 1970s, has now become a constraining factor. 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 major shortcoming of the literature on groundwater prices in India is that it generally does not record prices per unit volume of water; obviously a volumetric measure is necessary for a variety of reasons, including the assessment of the efficiency of water allocation within and across river basins. Somanathan and Ravindranath (2006) is an exception; their paper estimates marginal values of water and its elasticity of demand using data on water transactions in the Papagni watershed in southern India.

3. Principal Features of the Study Village

Sugarcane and paddy are the two most water intensive crops widely cultivated in North India. Our study site is Tabelagarhi village, in Baghpat district, selected from a 'dark' block[11] in the sugarcane belt of Western Uttar Pradesh. This is a freshwater region with good quality soils. By and large groundwater is the only source of irrigation for crops grown in this area. The water table in this area has witnessed a steady decline over the last few decades.

Tabelagarhi has 165 cultivating households. Cultivable land lies to the north, east and south of the residential neighborhoods. To the west, there is relatively little cultivation as much of the land there belongs to another village. The largest proportion of land is in the north, followed by the east.

Sugarcane is cultivated by all households in the village. It yields more than one harvest after a sowing; post first harvest, the crop is known as rattoon sugarcane (as opposed to freshly-sown (sugarcane). In this region, the first yield is lower than the yield of rattoon sugarcane and one crop can last for three seasons. Most farmers typically have plots of both crops in the field[12].

Sugarcane sowing takes place in April-May, and harvesting is between February and April. Rattoon sugarcane, on the other hand, is harvested between late October and January. Normally, organic manure is applied once, in May; fertilizer is applied at most twice (May and July), pesticide once. Field activities (which use labor, tractors and oxen) include preparation of land and sowing in April-May, field maintenance (such as weeding) in June-July, application of fertilizers etc., preparation and maintenance of channels for each irrigation, tying of cane in the field in September-October, and harvesting.

Sugarcane is irrigation intensive, with one irrigation pre-sowing, and regular irrigations thereafter. Conversations with experts and farmers at the site indicate that pre-monsoon irrigations are particularly crucial for plant growth. In 2004, the monsoon was delayed, and there was no rain in June and July. In this situation, it was a consensus opinion that during this time, one irrigation every 20 days was desirable. Water from tubewells is transported to plots via largely unlined channels. So there are seepage losses; but these are restricted by the relative proximity of other tubewells.

The village, as is the norm in Western Uttar Pradesh, is subject to erratic power supply. In May, power supply averaged 6-7 hours a day, went up to 8-10 hours in June, down to 3-5 hours in July (these three months saw no rainfall). For sugarcane, timely irrigations early in the season are critical to crop growth; thus the lack of regular electricity supply meant that in these summer months with no rain, tubewells seemed to

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11 Dark blocks are defined as areas where the quantum of groundwater used exceeds 85% of recharge.

12 Given this, we tracked the two varieties separately throughout the study. Thus if on a single plot of land, the farmer had both a rattoon and a new crop, these were categorized as two separate plots, and information on irrigation details, as of that of other inputs, were recorded separately.

be running flat out whenever there was power. We were told by farmers that for those who irrigated using purchased water, irrigation plans got delayed due to poor power supply and priority given to plots owned by tubewell owning farmers.

3.1 The Data

We first conducted a census of all households and tubewells in the village. We then constructed a random sample of 73 tubewells in Tabelagarhi, chosen from the north and east of the village (a few also from the south and west) roughly in proportion to the total numbers of tubewells located in those directions. We then identified all the plots (326) serviced by these tubewells; these plots belong to about 105 farmers. In fact, the sample is constructed so that all plots cultivated by these 105 farmers are included[13]. Including all plots serviced by a tubewell implies that we can compute the total amount of water discharged by each tubewell over the season, from plot-level irrigation data.

Data was collected at three levels: tubewell-specific, plot-specific, and farm household-specific. Plot-specific data (including details on source of irrigation, date of each irrigation, terms of the water transaction, information on labour and other inputs, and soil quality) is needed to estimate the demand for irrigation water. Tubewell data (including the depth of the tubewell, capacity of the motor, tubewell discharge, maintenance costs and history) helps to estimate water supply characteristics; for example, the cost of water extraction is lower for submersibles than for non-submersibles. Farm household data (including information on household members, and their education levels, and farm assets) can potentially help to identify farmer-specific effects on production. The field work was conducted once every two to three weeks, over the entire sugarcane cycle (April, 2004 to April, 2005). This frequency corresponded to the pattern of irrigations and large number of plots to be tracked, and helped in keeping the recall period low. We have also experimented with leaving booklets with educated farmers, to be filled in by them on a regular basis. More details on the variables collected are relegated to Appendix A.

3.2 Irrigation and Water Transactions in Tabelagarhi

The institutions by which water transactions are governed form a natural way of categorizing the plots in our sample. Of the 73 tubewells in our sample, 47 are under single, and 26 under joint ownership. Joint ownership is usually a consequence of inheritance by multiple sons. As indicated in Table 1.1, the average number of plots irrigated by single-owner tubewells is smaller than that irrigated by jointly-owned tubewells. However, as noted later, the unit area for plots irrigated by singly-owned tubewells is much larger (so that the total area irrigated is comparable).

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13 Farmers have multiple plots in our data set due to fragmentation of landholdings and division of cultivable space between freshly sown sugarcane and rattoon sugarcane.

The type of ownership has significant implications for the availability of surplus water for sale. For instance, sale of water is far more likely in single-owner than in joint-owner tubewells. Similarly, the average number of plots to which water sales occurred was much higher for singly-owned than for jointly-owned tubewells.

29 of the tubewells are 'submersible' and the rest are 'non-submersible'. All tubewells run on electricity. Submersible tubewells are much more expensive to purchase. For areas with low water tables, they are however the desired technology to possess. As shown in Table 1.2, on average for our sample, a submersible takes approximately 90 minutes to irrigate one *bigha* (1/5 acre), whereas a non-submersible takes about 2 hours. The costs of operating tubewells include the cost of electricity and maintenance costs. Electricity cost is an annual charge, based on the horsepower of the pump (Rupees 70 per month per horsepower). Submersibles not only have higher discharges, but are less prone to break-downs. The average number of times in the previous 12 months that repairs were effected to submersible tubewells was 1.5, half that for non-submersibles. Correspondingly, maintenance costs for submersibles were also lower.

It is also useful to examine the pattern of irrigation, disaggregated by category of plot, with category I referring to plots served by singly-owned tubewells, II referring to plots served by jointly-owned tubewells, while category III plots rely on purchased water (Table 1.3.). 117 plots in the sample source water from tubewells singly owned by the cultivators of these plots (category I); 122 source water from jointly owned tubewells (category II); 87 plots are being irrigated using purchased water (category III). The average plot size in the three categories is, respectively, 11.7, 5.7 and 4.7 *bighas*[14]. About half of the plots are under fresh sugarcane, and the rest under rattoon sugarcane.

The number of irrigations overall, favors category I plots that are watered through an owned tubewell; the least number of irrigations are given to plots which rely on purchased water (category III). More than the number of irrigations, their timing is crucial for plant growth. A key indication that plots that purchased water could not time their irrigations as well as others is the fact that in the dry summer months, a much lower percentage of these plots managed the recommended 4-5 irrigations. The average depth of each irrigation is also somewhat lower for these Category III plots.

Prices of water are quoted on a per hour basis. At the beginning of the season, a social consensus emerges and a water price is set in rupees per hour of use of a tubewell (Rs.15/hour in the data set). By and large, this is the price charged across the entire village, and buyers and sellers are price takers. This price is a slight markup on an average, per hour cost of operating a tubewell in the village. This apparent uniformity of prices has been noted elsewhere, and is cited as evidence that prices are determined as an outcome of a social contract.[15] Yet, when the variation among tubewells in term of the volume discharged per hour is taken into account, it is clear that prices are anything but uniform.

14 One bigha equals one-fifth of an acre, in this region.

15 See for example Dubash (2002).

We calculate the price of water *per unit volume* charged by a tubewell by dividing Rs. 15 by the measured volume of water that the tubewell discharges per hour. Thus the average price per bigha-inch (about 20,500 litres) of water across all tubewells is Rs.6.50[16]. There is substantial variation around this mean, with the 25th and 75th percentiles being Rs. 4.70 and 8 respectively. Submersible pumps (about 40% of the pump sets) discharge much more water than non-submersibles, so the volumetric prices of water from tubewells with submersibles is significantly lower. Pump sets of different vintages also show variation.

3.3 Yields, Soil Quality and other Inputs

As noted earlier, a distinguishing characteristic of the sugarcane crop is the practice of rattooning. Yields in the study area are higher for the rattoon than a fresh-sown crop, and begin to taper off after the first rattoon. Thus a fresh planting is necessitated every 2-3 seasons.

Further, there are two major varieties of sugarcane cultivated in this village: known as the 'early variety' and 'general variety.' We outline in Appendix B.3 the method used to aggregate across these varieties; the yields and input use for the two are quite similar.

In the study area, rattoon yields (at 68 quintals per bigha) are substantially higher than yields for the new crop (at 48 quintals per bigha). Table 1.4 summarizes yields of rattoon and non-rattoon sugarcane by category of plot, to examine whether the skewed pattern of irrigation volume and timing is reflected in differential yields.

As one might expect given the summary statistics on irrigation, yields are lower on plots with purchased water (both overall and when disaggregated by rattoon vs fresh-sown crops), but the differences, particularly for fresh-sown yields, are not substantial.

These differences in yields are, of course, mediated not just by the amount of irrigation, but by soil quality and other inputs as well. As noted earlier, soil samples were collected from each of the plots in the sample[17] and sent to the National Bureau of Soil Surveys and Land Use Planning for analysis. The soils in these areas are of good quality; about two-thirds of the plots in Tabelagarhi may be classified as "sandy loam", and another 22% as loam. Loamy soils are better, as they contain sand and silt in proportionate amounts, and are well drained. In contrast sandy loam soils are worse, in that these are coarse-textured, and typically require more irrigations. The remaining 10% of the plots are classified as clay loam, loamy sand, and silt loam.

16 By way of comparison, this is a little greater than half of the average water price that Somanathan and Ravindranath (2006) estimate for water transactions in the Papagni watershed in the southern states of Andhra Pradesh and Karnataka.

17 Samples were collected from three different corners of each plot and mixed together. These were then further subdivided into four parts of which two parts were kept, mixed and then finally put in a bag.

In terms of productivity, however, the impact of soil quality is discernible, if at all, only for category III plots, where yields on loam soils are 6 quintal per bigha higher than on sandy loam soils (Table 1.5).

Summary statistics for the other major inputs are presented in Table 2. With labor, all activities are summed across by type of activity (land preparation and sowing, weeding and digging, applications of irrigation and other inputs, tying of cane, harvesting) and by type of labor (hired casual labor and permanent labor, contractual labor, household labor, labor in exchange and other miscellaneous forms). Aggregate labor use by category of plot suggests that plots which purchase water are slightly more labor intensive.

Tractors are primarily used at the time of pre-sowing for land preparation, and for sowing. Oxen are also used for these activities; in addition, they are used for weeding and digging and for transporting sugarcane to sugar depots at harvest time. While oxen were used on almost all plots, tractors were used on about half of them. Tractors tend to be used on the larger-sized plots, so that their use is more on average on Category I plots than on others.

4. Models and Methods

4.1 A Model of Water Allocation in the Village

Before analyzing issues of water rationing and efficient water allocation, it is useful to have a stylized model of water allocation in the village. We describe here simplified versions of the two main kinds of institutions we observe: water sales from single-owner tubewells, and water sharing from jointly owned tubewells.

4.1.1 Water Sales from Single Owner Tubewells

At the beginning of the season, there is an agreement between the owner of a tubewell and prospective buyers, to supply water to the buyers' plots for the entire season. Suppose farmer s cultivates plot s, using water from his own tubewell t located on the plot. To keep the notation simple, let there be only one buyer of water from this tubewell[18]: so, suppose farmer s agrees to sell water, to a single plot i, cultivated by farmer i. The price of water that enters the agreement respects a centrally set per hour price. It is therefore determined as follows. A *per hour* price for using a tubewell and pump is set in a village-level agreement at the beginning of the season[19]. The price of water *per unit volume* from tubewell t is calculated as this per hour price divided by the discharge (volume of water discharged per hour) of tubewell t[20]. The *per hour*

[18] In the data set, the average number of buyers from single owner tubewells is 1.7.

[19] For the season in question, this was Rs. 15 per hour.

[20] Since different tubewells have different discharge rates, this results in different volumetric prices for water from different tubewells, even though the centrally agreed water price per hour was Rupees 15. The big source of discharge variation is type of tubewell, with discharges from submersible pumps being much larger than for their non-submersible counterparts.

price is set by the village as a rough markup on average cost of maintaining pumps and tubewells and payment for electricity. In our model, we simply take as given the village level per hour water price (and the implied water prices for each tubewell), explaining later why this price setting process may make sense.

Many of the input decisions for plots are made early in the season, when the extent of power availability through the season, and therefore water availability[21], is not known. To model this, let the amount of water available from tubewell *t* be a random variable W_t. We make the following, mostly simplifying, assumptions about W_t.

W_t is distributed on an interval $[0, \overline{w}_t]$, according to a continuously differentiable distribution function *G* (whose derivative is *g*). $\overline{w}_t$ is greater than the optimal irrigation volume choices that farmers *s* and *i* would make if there were no water constraint. Farmers *s* and *i* respectively make input choices $(x_{sj}),(x_{ij}),\ j \in \{3,...,k-1\}$ *before* it is known how much water W_t will actually be available from the tubewell (i.e., before the realization of W_t is known). (*j*=1,2, correspond to variables used in the estimation that are not explicitly required here: *j*=2 corresponds to a plot size variable, which is given, as we do not study acreage allocation decisions; *j*=1 corresponds to the constant term in the production function estimation; *k* refers to the irrigation variable) assume that farmers are risk-averse, maximizing the *utility* of profits with a twice continuously differentiable utility function *u*[22], satisfying $u' > 0,\ u'' < 0$. Assume for simplicity that the farmers have no alternative water source.

Suppose the input choices $(x_{sj}),(x_{ij}),\ j \in \{3,...,k-1\}$ have been made, and then the uncertainty on water is resolved, with W_t being the amount available from tubewell *t*. First, we analyze the allocation of this water if farmer *s* wishes to maximize profits[23].

Assumption 1. Farmer *s*'s water sales maximize profits

Let *p* be the sugarcane output price, $f((x_{sj}), x_{sk}, \beta)$ be the production function (β is a parameter vector), and q_{ik} be the price per unit of water paid by farmer *i* (the notation *q* is used for input price or input price vector). As mentioned before, this price is derived from a centrally set water price per hour of tubewell use, and is higher than c_t, the constant marginal cost of extracting water from tubewell *t*[24]. Farmer *s* can therefore *only decide the amount of water to sell*. We assume that *f* is twice

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21 All tubewell pumps in the village run on electricity

22 Assumed for simplicity to be the same for all farmers

23 Post the resolution of water uncertainty, maximizing profits or the utility of profits yields the same optimum.

24 The price per bigha-inch of water from tubewell *t* is simply the village level price of water per hour divided by the discharge from the tubewell (in bigha-inches per hour).

continuously differentiable, and that for every input $j \in \{2,...,k\}$, the first and second partial derivatives satisfy respectively $f_j > 0, f_{jj} < 0, f_{ij} > 0$. We also assume that at positive input prices, a unique, interior profit maximum exists that is characterized by the usual first-order conditions.

Let x_{sk}^* and x_{ik}^* respectively solve[25]

$$pf_k((x_{sj}), x_{sk}^*, \beta) = q_{ik} \tag{1}$$

$$pf_k((x_{ij}), x_{ik}^*, \beta) = q_{ik} \tag{2}$$

Let $\bar{x}_{sk}$ solve

$$pf_k((x_{sj}), \bar{x}_{sk}, \beta) = c_t \tag{3}$$

Proposition 1. *Suppose farmers s and i have chosen input vectors* $(x_{sj}),(x_{ij}),\ j \in \{3,...,k-1\}$ *.Suppose a volume of water becomes available and farmer s maximizes profits. Then the irrigation volumes of water* x_{sk}, x_{ik} *for the 2 farmers are*:

$$(x_{sk}, x_{ik}) = \begin{cases} (w_t, 0), & \text{if } w_t \le x_{sk}^* \\ (x_{sk}^*, w_t - x_{sk}^*), & \text{if } x_{sk}^* < w_t < x_{sk}^* + x_{ik}^* \\ (\min\{\bar{x}_{sk}, w_t - x_{ik}^*\}, x_{ik}^*), & \text{if } w_t \ge x_{sk}^* + x_{ik}^* \end{cases} \tag{4}$$

The proof is relegated to Appendix B.1. Since water sales fetch farmer *s* a revenue of Rupees q_{ik} per unit, he will use all available water on his plot, and sell none, as long as the value of the marginal product of water (MPW) on his plot exceeds q_{ik}. For larger quantities of water, he will use water on his own plot to the point that its value of MPW equals the water price, and sell the rest to farmer *i*. He will do so until farmer *i*'s demand is sated, and use additional amounts on his own plot again, until the value of MPW there decreases to equal the marginal cost of extraction. We discuss briefly the implications of the proposition for this paper. Of course, this allocation of water is not efficient. Once the vectors of other inputs are chosen for the two plots, efficiency of water allocation requires that its marginal product on the two plots be equal:

$$f_k((x_{sj}), x_{sk}, \beta) = f_k((x_{ij}), x_{ik}, \beta) \tag{5}$$

The allocation in Proposition 1 almost nowhere satisfies Eq.(5). Note also that if water

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25 Eqs.(1) and (2) refer to irrigation volumes such that the values of MPW on plots *s* and *i* equal the price per unit volume of water from tubewell *t* . Eq (3), to the irrigation volume at which the value of the MPW on plot *s* equals the marginal cost of water extraction from tubewell *t*.

Note also that the observed allocation from the data implies that the MPW on the tubewell owners' and water buyers' plots are closer to each other than would be the case under the Proposition 1 allocation. This reduces crop yield losses, relative to the outcome in Proposition 1. The water allocation we observe in the village is therefore better understood in terms of the assumption below, an alternative to Assumption 1.

Assumption 1A. Water Allocation is governed by a Social Contract

The reason that there is inefficiency in the presence of water rationing is that farmers transacting in water do not or cannot make any transfers save the fixed water price. Given that this is so, the observed allocation, and anecdotal evidence, suggests that a *social contract* operates to check crop yield losses. We model this simply by assuming that the farmers are governed by the following kind of water sharing arrangement: When the available water $w_t < x^*_{sk} + x^*_{ik}$, farmers *s* and *i* divide it in some positive proportions $\phi_{st}(w_t), \phi_{it}(w_t)$ according to either a prior mutual agreement, or an agreement governed centrally by the village (with farmer *i* paying the unit price q_{ik}). When $w_t \geq x^*_{sk} + x^*_{ik}$, given the price q_{ik} of water, the allocation is as given in Proposition 1. Assume for simplicity that the functions $\phi_{st}(w_t), \phi_{it}(w_t)$ are continuous, and that $\lim_{w_t \uparrow (x^*_{sk} + x^*_{ik})} (\phi_{st}(w_t), \phi_{it}(w_t)) = (x^*_{sk}, x^*_{ik})$. This property makes the allocation efficient if $w_t = x^*_{sk} + x^*_{ik}$, a reasonable assumption in trying to model a social arrangement that attempts to restrain the extent of water misallocation.

Such a social contract is not necessarily coercive. Most farmers in the village have multiple plots. The plots of a farmer are typically disparate in size, and owing to fragmentation of land, not all contiguous. As a result, it is almost never the case that all of a farmer's plots have tubewells. Therefore, a farmer that sells water from a tubewell on some plot, generally also buys water for some other plot. In a scenario with water rationing, the social contract cuts into the farmer's profits as a water seller, on account of unprofitable water sales. However, it also adds to his profits on plots where he buys water, by providing water where none would be available if water sellers maximized profits from water sales. Data analysis in Section V will show that the latter effect is much larger. Although we do not model how the functions ϕ_{st}, ϕ_{it}, or the village-level water price per hour are determined (simply taking them as given), it is easy to see how this kind of social contract can be an equilibrium outcome, for example, of a village-wide bargain, or a repeated game, or an evolved social norm.

We now describe the choice of all inputs (including water, taking acreage as given) under a social contract. Let q_j, $j = 3,...,k-1$ be the prices of inputs other than water.

These are assumed to be the same across farmers, for simplicity. Let[26]

$$x_{sk}^{h}(w_t) = \min\{\bar{x}_{sk}, w_t - x_{ik}^{*}\} \tag{6}$$

Farmer s's problem before the amount of water available is known is to choose an input vector $(x_{sj})_{j=3}^{k-1}$ in order to maximize

$$E[u(\pi_s)] = \int_{x_{sk}^{*}(x_{sj})+x_{ik}^{*}}^{\bar{w}_t} u(pf((x_{sj}), x_{sk}^{h}(w_t), \beta) - \sum_{j \neq k} q_j x_{sj} - c_t x_{sk}^{h}(w_t) + (q_{ik} - c_t)x_{ik}^{*}))g(w_t)dw_t +$$

$$\int_{0}^{x_{sk}^{*}(x_{sj})+x_{ik}^{*}} u(pf((x_{sj}), \phi_{st}(w_t), \beta) - \sum_{j \neq k} q_j x_{sj} - c_t \phi_{st}(w_t) + (q_{ik} - c_t)\phi_{it}(w_t))\, g(w_t)dw_t \tag{7}$$

After a couple of cancellations, we may write

$$\partial E[u(\pi_s)] / \partial x_{sj} = \int_{x_{sk}^{*}(x_{sj})+x_{ik}^{*}}^{\bar{w}_t} u'(.)(pf_j((x_{sj}), x_{sk}^{h}(w_t), \beta) - q_j)g(w_t)dw_t +$$

$$\int_{0}^{x_{sk}^{*}(x_{sj})+x_{ik}^{*}} u'(.)(pf_j((x_{sj}), \phi_{st}(w_t), \beta) - q_j)g(w_t)dw_t \tag{8}$$

where the argument of the marginal utility $u'(.)$ is suppressed.

Define $X_{sk} = \begin{cases} \phi_{st}(w_t), \text{ } if \ w_t < x_{sk}^{*}(x_{sj}) + x_{ik}^{*} \\ x_{sk}^{h}(w_t), \text{ } if \ w_t \geq x_{sk}^{*}(x_{sj}) + x_{ik}^{*} \end{cases}$ (9)

to be farmer s's random allocation of irrigation water. Then, the first-order condition for an interior maximum equates Eq.(8) to 0, and may be written as

[26] Eq.(6) gives the amount of water that plot s would use, if the total water available is more than what is required to equate the values of MPW of plots s and i to the water price from tubewell t (see the discussion below).

$$E_{X_{sk}}\left[u'(X_{sk})(pf_j((x_{sj}),X_{sk},\beta)-q_j)\right]=0 \quad (10)$$

where we have suppressed all arguments of marginal utility u' other than X_{sk}. Note that Eq.(10) implies

$$E[pf_j((x_{sj}),X_{sk},\beta)-q_j] = -[Cov(u'(X_{sk}),pf_j((x_{sj}),X_{sk},\beta)-q_j)/E(u'(X_{sk}))] > 0$$
(10')

The inequality above obtains due to risk aversion: u' is decreasing in X_{sk} (whereas the marginal product f_j is increasing in it). We will assume for simplicity that the first-order conditions characterize farmers' optimal choices, and have a unique solution. Eq.(10') implies that at the optimal choice of inputs *j*=*3*,...,*k*-1, the relevant marginal value products are greater than the corresponding input prices.

Farmer *i* chooses $(x_{ij})_{j\neq k}$ to maximize

$$E[u(\pi_i)] = (1-G(x^*_{sk}+x^*_{ik}(x_{ij}))).u(pf((x_{ij}),x^*_{ik},\beta)-\sum_{j\neq k} q_j x_{ij} - q_{ik}x^*_{ik}) \; +$$

$$\int_0^{x^*_{sk}+x^*_{ik}(x_{ij})} u(pf((x_{ij}),\phi_{it}(w_t),\beta)-\sum_{j\neq k} q_j x_{ij} - q_{ik}\phi_{it}(w_t))g(w_t)dw_t \quad (11)$$

Defining farmer *i*'s random water allocation by

$$X_{ik} = \begin{cases} \phi_{it}(w_t), & if \quad w_t < x^*_{sk}+x^*_{ik}(x_{ij}) \\ x^*_{ik}, & if \quad w_t \geq x^*_{sk}+x^*_{ik}(x_{ij}) \end{cases} \quad (12)$$

we have in similar fashion farmer *i*'s first-order conditions for an interior maximum:

$$E_{X_{ik}}\left[u'(X_{ik})(pf_j((x_{ij}),X_{ik},\beta)-q_j)\right]=0 \quad (13)$$

so that

$$E[pf_j((x_{ij}), X_{ik}, \beta) - q_j] = -[(Cov(u'(X_{ik}), pf_j((x_{ij}), X_{ik}, \beta) - q_j) / E(u'(X_{ik}))] > 0$$
(13)’

Note that the optimal choice of the inputs (x_{sj}), (and therefore of x_{sk}^*), depends on x_{ik}^*, which is a parameter in farmer *s*’s optimization problem. Similarly, the optimal choice of (x_{ij}), (and therefore x_{ik}^*), depends on x_{sk}^*. So we will define an equilibrium allocation as an allocation of inputs (including random water allocation to the two plots) that is mutually consistent.

Definition 1. *An equilibrium allocation is a tuple* $((x_{sj})_{j \neq k}, X_{sk}, (x_{ij})_{j \neq k}, X_{ik})$ *such that*

(i) (x_{sj}) *is a solution to Eq. (10);* (x_{ij}) *is a solution to Eq.(13); the parameters* x_{sk}^*, x_{ik}^* *in, respectively, farmer i’s and farmer s’s optimization problems are solutions to Eq.(1) and Eq.(2) respectively.*

(ii) *The random water allocation specified by the social contract uses* x_{sk}^* *and* x_{ik}^* *specified in* (i) *above:* X_{sk} *is given by Eq.(9),* X_{ik} *is given by Eq.(12).*

Proposition 2 asserts the existence of equilibrium.

Proposition 2. *An equilibrium allocation exists.*

The proof of this proposition is in Appendix B.1. Let us summarize the contrasting implications (for the data) of water allocations governed by profit maximization from water sales (Assumption 1, leading to Proposition 1) as opposed to a social contract (Assumption 1A, and Proposition 2). Suppose we evaluate values of MPW for different single tubewell owner and water buyer plots, using the observed choices of inputs (including water). Comparing them to water prices from these tubewells, we find that the values of the MPW for both kinds of plots exceed the water prices. Since water selling plots have marginal product values above the water sale price, under Assumption 1 of static profit maximization this should imply that water buying plots are not gettingany water. If this is not so, a social contract assumption like Assumption 1A, and the water allocation therein explain the data better[27].

[27] There are no implications for similar marginal product – input price comparisons for other inputs. For those, Eq.(13) and (16) show that comparisons work only in an *expected* sense. They are not meaningful with the *particular realization* of the water consumption random variables in the data.

4.1.2. Water Sharing from Jointly Owned Tubewells

Joint ownership of a tubewell occurs between brothers, due to inheritance. The joint owners share water from the tubewell, and the costs of maintenance. But they are separate cultivators. Usually, the largest stakeholder in the tubewell is the first to receive water in an irrigation cycle, followed by other partners in decreasing importance of their investment share. In a setting of limited power availability, arranging for efficient water sharing requires that farmers agree to use less water than the amounts that equate the marginal value products of water on their plots with the marginal cost of water extraction. How close the allocation is to efficient is an empirical question that can be answered using the MPW estimates and Simulation 1 (Section 5).

4.2. Estimating the Production Function

The first part of our empirical exercise is to estimate a sugarcane production function for the village. A practical problem with estimating a production function at the village level is lack of variation in the explanatory variables across plots. If the input prices faced by different farmers in the same village are the same, their input choices are very similar. As discussed above, we do not face this problem since there is appreciable variation in water prices across plots; there is also some variation in soil quality, and a little variation in rental charges for tractors and oxen. Thus relative prices of inputs vary across plots, and price-taking profit maximizing farmers are expected to vary their input demands accordingly.

Using data on plot level inputs and outputs, consider estimating a production function by taking logs in Eq.(14) below:

$$y_i = f(x_i, \beta)\varepsilon_i \tag{14}$$

Here, y_i, x_i, ε_i are, respectively, output, a *k*-dimensional input vector (of which the *k*th input is water), and error on plot *i*, and β is a *k*-dimensional parameter vector.

A major difficulty with estimating Eq.(14) (or indeed with estimating cost or profit functions) is a well-known identification problem (Marschak and Andrews(1944). If there are variables that the farmer, but not the econometrician, observes, then profit maximizing farmers' input choices are correlated with the error term in the regression, and the estimates are biased. In the context of agriculture, such unobserved variables could include soil quality, farm management practices, plant health characteristics. This is a long-recognized problem, to which various solutions have been offered. (See for example Griliches and Mairesse (1998), Olley and Pakes (1996), Levinsohn and Petrin(2003)). Often, instruments (mostly, input prices) are used to get around the endogeneity problem; several recent papers use panel data methods. In the present paper, input prices except water price are not too different across plots, and cannot be used as instruments. We do not have panel data. So we have attempted to exploit two different kinds of information that we collected. First, we have plot-level data on soil quality, the amount of family labor used, and several other such variables which are arguably exogenous and can be used as instruments. Moreover, we exploit the fact that most farmers in the data set cultivate multiple plots; thus plant health characteristics and other farmer-specific characteristics are sought to be captured by farmer-specific dummies. We therefore estimate the equation

$$y_i = f(x_i, \beta) a_t \varepsilon_i \tag{15}$$

where a_t is a farmer *t*-specific shock unobserved by the econometrician (where farmer *t* cultivates plot *i*), which we can estimate using a dummy for farmer *t*[28].

In our econometric work, we have experimented with several functional forms and find that the simple Cobb-Douglas production function works best. For example, we cannot reject the hypothesis that coefficients of all the interactive and nonlinear terms of the Translog function (which nests the Cobb-Douglas as its linear part) are jointly insignificant[29]. A larger study, encompassing many villages, would presumably have enough variability to better address the question of appropriate functional form; the present paper uses the Cobb-Douglas as a good first approximation[30]. Our production model is therefore

$$\ln(y_i) = \sum_{j=1}^{k} \beta_j \ln(x_{ij}) + \sum_{t=1}^{T} \gamma_t d_t + \lambda d_c + u_i \tag{16}$$

where *i* indexes plots, *t* indexes farmers, $x_{i1} = 1$, for all *i*, $d_t = 1$ if plot *i* is cultivated by farmer *t*, and is zero otherwise; d_c equals 1 if plot *i* has a rattoon crop, and is zero if the crop is fresh sown sugarcane. The explanatory variables x_{ij} are plot size, manure, fertilizer value, labor, tractor and oxen hours, and irrigation volume.

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28 We find that including farmer fixed effects gives reasonable results; our instruments are not good enough to improve on these. For example water prices are too weakly correlated with irrigation volumes. This is as expected in the presence of water rationing and a social contract dictating water allocation.

29 The F(1,281)-statistic corresponding to the null that the higher order terms of the Translog are all zero evaluates to 0.82. Since the probability exceeding this value is 0.365, we cannot reject the null.

30 The specific discomfort with the Cobb-Douglas functional form is that it restricts the elasticity of substitution between inputs in a drastic fashion, and also imposes symmetry in this across all pairs of inputs.

4.3 Assessing Allocative Efficiency

We use the estimated production function to assess efficiency of water allocation as follows. In multiplicative form, the fitted value of Cobb-Douglas output on plot *i*, evaluates to $f(x_i,\hat{\beta}) = e^{(\hat{\beta}_1 + \sum \hat{\gamma}_t d_t + \hat{\lambda} d_c)} x_{i2}^{\hat{\beta}_2} ... x_{ik}^{\hat{\beta}_k}$. Correspondingly, the estimate of marginal product of water on the plot equals

$$f_k(x_i,\hat{\beta}) = e^{(\hat{\beta}_1 + \sum \hat{\gamma}_t d_t + \hat{\lambda} d_c)} \hat{\beta}_k x_{i2}^{\hat{\beta}_2} ... x_{ik}^{\hat{\beta}_k - 1} \quad (17)$$

(where f_k is the partial derivative of *f* with respect to x_k (the volume of water)). Allocative efficiency requires that this marginal product be the same on every plot. We first assess whether these marginal product numbers vary significantly across plots.

Next, we conduct an examination of whether there is water rationing. Following the discussion of the model in Section 4.2, *in the absence* of a water constraint, we should observe the following. For plots buying water, profit maximization implies that the value of the MPW should equal the unit price of water. For plots with owned tubewells, the value of the MPW should equal the marginal cost of water extraction from that tubewell. On the other hand, values of MPW significantly larger than water prices/costs imply that water is rationed. So we first check whether the (value of) the marginal product of water (Eq.(17)) on plot *i* is significantly different from the price q_{ik} (or marginal cost) of water for the plot. We do this by constructing a 95% confidence band (a_i, b_i) around Eq.(17), constructed using asymptotic theory. The details of the construction are in Appendix B. If $q_{ik} \in (a_i, b_i)$, then the marginal product of water is not significantly different from the water price; in this case, the source of allocative inefficiency is the differences in water prices / costs of water extraction across plots. On the other hand, if $q_{ik} < a_i$, then plot *i* is rationed for water.

We find there is substantial water rationing, and that the water allocation indicates the existence of a social contract akin to Assumption 1A, rather than tubewell owners choosing water sales amounts to maximize profits.

A note on estimating the marginal cost of water extraction from a tubewell. The marginal cost of water extraction does not include a charge for electricity, since those are lump sum annual charges. But it can depend on the number of pump breakdowns (and the cost of repair), if the number of hours of operation is positively related to the number of breakdowns. We model the number of breakdowns as a *Poisson* process, estimate the *Poisson* parameter from data on hours of operation and number of breakdowns for each pump. From this we can estimate a marginal cost of water extraction for each tubewell. See Appendix B.3 for details.

4.4 The Impact of Allocative Inefficiency and Policy Alternatives

4.4.1. Simulation 1: Losses from Inefficient Water Allocation

First, we examine the extent of profit and crop output losses owing to inefficient water allocation in the data. The specific question is: *What would the outputs from the sample plots be if the total observed water* ***from each tubewell*** *in the sample is allocated efficiently across the plots that are serviced* ***by that tubewell*** *?*

Suppose for every plot *i* in the data set, the choice (x_{ij}) of inputs other than irrigation has been made as in the data. Suppose the constant marginal cost of water extraction from tubewell *t* is c_t, and let *U(t)* be the set of all plots in the sample that are serviced by tubewell *t*. Let w_t be the total volume of water discharged from tubewell *t* in the data. An efficient allocation $(\hat{x}_{ik})_{i \in U(t)}$ of water would be a vector that maximizes

$$\sum_{i \in U(t)} [pf((x_{ij}), \hat{x}_{ik}, \beta) - c_t \hat{x}_{ik}]$$, subject to the constraints

$$\sum_{i \in U(t)} \hat{x}_{ik} \leq w_t \text{, and for all } i \in U(t), \hat{x}_{ik} \geq 0. \qquad (18)$$

We solve this problem, evaluated at the estimated parameter vector $\hat{\beta}$, for each tubewell in the data set. Then we compare the total simulated output with the total output in the sample.

In the above simulation, as well as in all others, we make the simplifying assumption that the mapping from tubewells to user plots stays the same. Given that water is transported through unlined water channels, this mapping is largely determined by proximity of plots to particular tubewells. This paper does not address questions of changes in water transport technology (such as a system of pipes); therefore, it is reasonable to retain the tubewell-user plot mapping as it is.

4.4.2. Simulation 2: The Value of the Social Contract

As discussed earlier, the data indicate that even though tubewell owners' plots are short of water (with marginal value products of water exceeding the water price), they sell substantial amounts of water to other plots at those water prices. The degree of social cooperation required to do this is present perhaps due to the relatively homogeneous social and economic composition[31] of the village. In the absence of this, one would expect outcomes closer to the allocation described in Proposition 1.

[31] Most farmers belong to the same caste, all farmers grow sugar cane, have fragmented holdings and depend on groundwater for irrigation.

Simulation 2 therefore answers the following question: *What would be the impact on yields if tubewell owners maximize profits and allocate water according to Proposition 1*?

We implement this simulation for each tubewell in the sample. We work out the total volume of water that each tubewell *t* discharged, and allocate it according to Proposition 1. As a practical matter, we find that for each tubewell, the total volume of water in the sample is either so insufficient that this allocation leaves some water buying plots with no water at all, or moderately insufficient, so that they get water left over after the MPWs on the owner's plots are equalized with the water price of the tubewell.

4.4.3. Simulation 3: (Alternative Policy Simulations) Implications of reliable power supply and unit pricing

A common feature of the sugarcane belt is the low marginal cost of extracting water, owing to the absence of groundwater pricing and a zero marginal cost of electricity use. By itself, this would encourage overuse of water. The observed absence of overuse is explained by the stringently constrained and erratic power supply. As poor power supply is said to adversely affect plant growth, we simulate yields in the presence of reliable supply of power.

However, the lump sum charges for electricity leaves the power supplier no incentive to provide reliable power. Therefore, *this simulation examines the potential impact of two major policy instruments that can be used: metered, unit pricing of electricity to provide incentives to the power provider, and reliable power supply to relax water rationing.* With unit pricing at remunerative levels, the power supplier has an incentive to supply power. The results in the next section show that there is a wide gap between the values of the marginal product of water on plots and the marginal cost of water extraction. This suggests that farmers could be willing to pay substantial unit prices for electricity while increasing profits as well, provided power is reliably supplied. However, if it is profitable to use water at a certain unit power price, the estimation results also suggest that farmers will use *more* water than they could in the water rationed context observed in the data. So, the simulation tracks the effect of different unit prices of power, and reliable power supply, on yields, profits, water use, and power revenue to the power provider.

Modeling Simulation 3

Consider the ramifications of reliable power supply and unit pricing on water allocation in our context. Suppose the power provider sets a unit price of , and for convenience suppose there is no lump sum charge for power use. For each tubewell, the unit electricity price translates to a unit cost of water extraction. This cost varies across tubewells as their discharges and vintages (hence repair costs) vary. At the village level, a central *per hour* price of tubewell use is set, based on the unit costs of water extraction, at which for each tubewell, it is profitable to supply water.

Now consider the problem of a farmer of plot *s*, that has tubewell *t*, and suppose that *B(t)* is the set of plots that buy water from this tubewell. With reliable power supply, the high density of tubewells implies there is no water constraint, i.e. $w_t \geq x_{sk}^* + x_{ik}^*$. In the absence of water uncertainty, risk-averse farmers in effect maximize profits. Suppose that farmer *s*'s optimal input choices are $((\hat{x}_{sj}), \hat{x}_{sk})$, and those for the water buyers are $((\hat{x}_{ij}), \hat{x}_{ik})_{i \in B(t)}$. If the water price q_{ik} per bigha-inch is greater than the unit cost of extraction c_t from the tubewell, farmer *s* would supply the entire demand for water from the plots *B(t)*. So, for him,

$$((\hat{x}_{sj}), \hat{x}_{sk}) \in \arg\max[pf((x_{sj}), x_{sk}, \beta) - \sum_j q_j x_{sj} - c_t x_{sk}] \tag{20}$$

And for all plots $i \in B(t)$,

$$((\hat{x}_{ij}), \hat{x}_{ik}) \in \arg\max[pf((x_{ij}), x_{ik}, \beta) - \sum_j q_j x_{ij} - q_{ik} x_{ik}] \tag{21}$$

That is, *the optimization problems of the different plots can be solved separately*, because there is no common water constraint. Similar reasoning applies to plots that share water, or buy water from, jointly owned tubewells. From the solutions to plot level optimization problems, we derive per bigha averages for ouput, profit, irrigation volume, and power revenue, and compare them with the baseline numbers observed in the data.

5. Results and Discussion

5.1. Evidence on Rationing

Table 3 presents the Cobb-Douglas production function estimates. All variables except fertilizers have the right sign and all but manure are significant. The largest of the elasticities are for plot size (0.742), oxen (0.1254), tractor (0.0905), labor (0.0762), and irrigation (0.0643). Fertilizers and manure have insignificant coefficients. As evidenced by the crop dummy, rattoon sugarcane in this region gives somewhat higher output than fresh sown sugarcane. Eight farmer dummies are significant and sizeable (absolute values between 0.2 and 0.4).[32]

Using these estimates, we follow Appendix B.2 to derive estimates of the marginal product of water (MPW) for each plot, and a 95% confidence interval around each of them. See Table 4. For the sample overall, the average *value of* MPW (the MPW times the sugarcane price of Rs. 102 per quintal) is about Rupees 16.6 per additional

32 We also experimented with alternative specifications; for example, a dummy for whether the plot is a purchaser of water. This turns out to be insignificant, and does not greatly affect the other estimated coefficients. This suggests that the estimates of MPWs are fairly robust.

bigha-inch of water (1 bigha-inch of water equals about 20,558 litres). The 95% confidence intervals vary from about Rupees ± 0.3 to ± 0.4. The mean marginal value product is about 2.5 times greater than the mean water price of Rs. 6.53 per bigha-inch. A closer investigation bears out the suggestion of widespread water rationing: the value of MPW is significantly larger than the water price for 308 of the 326 plots.

Since this is the case, a tubewell owner seeking to maximize profits on a plot of his own should choose irrigation volumes such that the value of the MPW on this plot equals or drops below the water price he charges for selling water; and sell water only *after* meeting this water requirement (as in Proposition 1 in Section IV). Instead, the data show that plots which buy water get appreciable amounts, given the rationing. So, a *social contract* operates to distribute water more equitably than profit maximization by water sellers would permit.

Plots with own tubewells are relatively less water-rationed. Table 4B shows that the mean marginal value product of water for plots with own tubewell is Rupees 11.87, that for plots irrigated from a jointly-owned tubewell is Rupees 19.92 (this is influenced significantly by a few large outliers), and for plots irrigated using purchased water, it is Rupees 18.43. An analysis of variance of the MPWs (marginal value products divided by Rs.102) shows that less than half the variation of the total sum of squares (9.6 of 20.6) is attributable to within-group variation (i.e. variation of MPWs across plots served by the same tubewell). In a setting of limited power supply and unlined water channels, tubewells serve only plots located close to them. As borne out also by the results of Simulation 1 below, it is remarkable how close the MPWs of plots serviced by the same tubewell are, suggesting that the gains from reallocating water locally would be relatively little.

5.2. Policy Simulations

Simulation 1. What would be profits and output from the sample plots if the total observed water *from each tubewell* in the sample is allocated efficiently across the plots that are serviced *by that tubewell* ?

This exercise simulates an environment in which the observed water volume from each tubewell is distributed to its recipient plots in order to maximize joint profits (gross of other input costs). Since all the recipient plots face the same output price and marginal cost of water extraction, and since there is water rationing (the water constraint binds), this exercise is the same as that of maximizing joint output. As indicated in Table 5, redistributing water results in an average gain of less than 0.2 quintals per bigha, with the highest gain of 1 quintal per bigha (a gain of about 2%; in value, Rs.102 per bigha) on plots which purchase water.

From the results of Simulation 1, we infer that the social contract appears to work extremely well, to minimize losses in overall yields in the face of water rationing. Simulation 1 also shows that at the observed levels of inputs and given the estimated irrigation elasticity, *incremental water alone has limited positive effect on output.*

Simulation 2. What would outputs be if the total observed water *from each tubewell* is allocated to the plots it services so as to enable the tubewell owner to maximize profits ?

Table 6 displays the simulated plot outputs if water from each tubewell is allocated according to Proposition 1; i.e., if a profit maximizing tubewell owner sells water only after allocating enough to his own plots to equate the marginal value products on them to the water price. The reallocation of water that this entails towards *tubewell owners'* plots increases outputs on those by 0.7 quintals per bigha, but average yields on plots that buy water drop from 53.7 to 16.30 quintals per bigha! As a result, overall yield declines from 57.51 to 48.14 quintals per bigha. The numbers can be interpreted as follows. On average, tubewells that sell water service tubewell-owners' and water buyers' plots in the ratio 3:1 (in terms of area). A reallocation in accordance with Proposition 1 adds some water to each plot of the tubewell owner; due to the somewhat low irrigation elasticity, the positive effect on output is not too pronounced. On the other hand, given that the area under water buyers' plots is much smaller, their overall water use in the sample is also relatively small. The above reallocation therefore takes away a lot of this water, resulting in a sharp fall in output.

Simulation 2 demonstrates the value of the social contract. It adds about 9 quintals per bigha (19.5% larger than it would have been in the absence of a social contract), worth more than Rupees 900 per bigha of output, on average on village plots. For a tubewell owner who irrigates 75% of his plots with his own tubewell, and a 25% fragment elsewhere using bought water, this is also the value of the social contract: what he loses due to it on own tubewell irrigated plots, he makes up on plots that buy water, for an overall gain of 9 quintals per bigha.

Simulation 3. What would be the effect of unit pricing of power (at different levels), and reliable power supply, on yields, profits, irrigation volumes and power revenue?

<u>Basic Assumptions:</u> In the data set, tubewell pump set owners are charged Rupees 70 per horsepower per month. Most farmers report pumps to have 10 horsepower, so annual charges are about Rupees 8700 (8400 + other minor charges). But in actual fact, almost all pumps run on 20 horsepower[33]. We base our simulations on this fact. We assume for simplicity that the power provider does not charge any lump sum fee, so only a price per kw hour of power set. Thus a unit power price of rupees y per kw hour translates to approximately rupees 15y per hour, for a 20 horsepower pump[34]. Dividing this by the discharge from the tubewell, and adding to that the estimated marginal cost of water extraction from this tubewell[35], we get a simulated unit cost of extracting

[33] This is not surprising. Given the shortage of electricity to pump water, farmers compensate by having more tubewells and horsepower than would otherwise be necessary, in order to pump up water as quickly as possible.

[34] Since 1 horsepower is approximately ¾ of a kilowatt. Unless the pump is simply idling, a running 20 HP pump consumes close to that, if the depth of the water table is sufficiently low.

[35] The estimate of the Poisson parameter is 0.002 for non-submersibles and 0.0005 for the submersibles. Correspondingly, on average the marginal costs of extraction for non-submersibles and submersibles are, respectively, Rs. 1.45 and Rs. 0.3 per bigha-inch of water.

1 bigha-inch of water. The simulated village-level water price (per hour of use) is assumed to just cover the average cost of the highest cost tubewell. This is consistent with 2 implications from the data set; first, the village water price is roughly comparable to the mean average cost of water extraction per hour plus the average fixed cost. Second, it is higher than the marginal cost of water extraction of all tubewells, so that all tubewell owners will wish to sell surplus water. From the simulated village per hour water price, we derive the implied water price per bigha-inch, for each tubewell in the sample. Due to the village norm of setting water price close to extraction cost, the water prices paid by water buyers are not too much higher than the unit cost of extraction. This makes for a water allocation which is reasonably close to an efficient one.

With the water prices and extraction costs in place, and other input and output prices as given in the sample, we endow each plot with the estimated production technology, and allow each plot in the sample to choose labor, tractor and oxen hours, and irrigation volumes, in order to maximize profits as described by Eqs.(20) and (21)[36]. Note that we hold fixed the mapping of tubewell to user plot; this determines specific water costs or prices for each plot.

The simulation. We vary the unit power price from Rs.1.80 (lower than estimates of average power generation costs of Rs.2 in India; power transmission and distribution costs are additional) to Rs.4.50 per kilowatt-hour (kWhr). The latter roughly corresponds to commercial (industrial) rates in several parts of the country; commercial rates also include a flat charge of about Rupees 50 per kWhr of load sanctioned.

The results are summarized in Table 7 and Figures 1 and 2. Sample values for yield, profit per bigha, irrigation volume per bigha and power revenue per bigha are respectively 58.22 quintals, Rs.2490, 30 bigha-inches and Rs.270[37]. These are recorded in Table 7 as the "sample" scenario; for which the unit power price is zero (and there is a lump sum monthly charge of Rs.70 per reported horsepower). At a power price of Rs.4.50 per kw hour (close to rates charged to industry), irrigation volume is 30.20 bigha-inches, yield is about 60.85 quintals, profits are above Rs.2032, and revenue to the power provider is Rs.851. As the power price is lowered gradually to Rs.1.80, irrigation volume increases to about 34.51 bigha-inches (thus increasing on average 0.16 bigha-inch per 10 paise reduction in the power price), yield increases slowly, to reach about 63.43 quintals, power revenue per bigha decreases to Rs.384.62.

Figure 1 provides a visual understanding of the relationship between irrigation volume and yield. Note first that at 30.21 bigha inches, the yield of 60.8 quintals is 2.6 quintals above the sample yield of 58.2 quintals, for which irrigation is a comparable 30.02 bigha-inches. From the knowledge of Simulation 1, we can attribute less than 0.2 quintals of this increase to better water allocation than in the sample. The rest of it is attributable to slightly higher input use in Simulation 3, relative to the sample; with

36 Acreage and the variables with insignificant estimates (Table 3) are not optimized over.

37 Profit is calculated as revenue minus wage cost, rental costs of tractors and oxen, fertilizer cost and water cost; and cost of power for tubewell owners. We do not subtract land rent. Incidentally, in this area, there is very little land given out on rent. The wage cost includes an imputed wage for family labor. Family labor can be quite important in several activities.

positive cross-partial derivatives in the production function, this increases yield at the same level of water-use as in the sample[38]. Yield increments thereafter are slow and diminish at higher irrigation levels.

Table 7 shows that for power prices up to Rs.2.50 per kWhr, farmers' profits and the power supplier's revenues are both greater than their sample values; the significantly higher simulated yields can therefore pay for electricity prices that cover the cost of power generation. We noted earlier that in the present setup of lumpsum power payments based on pump horsepower, there is widespread underreporting of horsepower. Accurate assessments of pump horsepower would decrease sample profits and increase sample power revenue by Rs.270 per bigha each. Under such an alternative baseline scenario, Table 7 suggests that power prices between Rs.2.70 and Rs.3.60 per kWhr are consistent with simulated profits and power revenue being larger than their baseline values.

Simulation 3 therefore implies that even in the presence of a social contract that results in a close-to efficient allocation of scarce water, a switch to remunerative power pricing is feasible, acceptable to both farmers and power providers, and will result in a substantial increase in yields. However, water use is heavier than in the sample at power price levels that are politically acceptable[39].

Sustainability. What markup on the unit electricity price would make water use intertemporally efficient ?

Questions of sustainability of water use in the region are closely connected to intertemporally efficient water extraction from an aquifer with recharge. The problem of falling water tables, in this context, is one of overextraction of groundwater. An individual farmer may not take into account the negative externality of his water use on other farmers. In fact individual farmers are small enough that their individual water extraction has a negligible impact on aquifer depletion, so in each season, they may extract water until the single-period marginal revenue from it equals the marginal extraction cost. This is clearly inoptimally large. We provide in this section estimates of a markup on the unit social cost of power supply that can align an individual farmer's water extraction rate with what is socially optimal. An in-depth study of intertemporal issues is beyond the scope of this paper, as this requires knowledge of the groundwater hydrology of the region, data on water depletion over time, and on characteristics and profitability of competing crops. So the estimates here are indicative rather than definitive, and designed as a starting point for careful future studies.

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38 The lower input use in the sample is due to the choices of risk-averse farmers to uncertainty in water supply. As shown by Eq.10' and 13', at the input levels chosen by risk-averse farmers, the marginal value product of an input exceeds the input price.

39 The simulated yields are considerably higher (exceeding the average sample yield by at least 25% at the highest tariff level in the simulation) if they are evaluated after setting insignificant parameter estimates of the production function to zero. So the results for simulated yields (and therefore for profits) that we report ought to be viewed as a lower bound to the gains that are possible from a switch to reliable, adequate electricity to power the tubewell pumps.

Suppose that aquifer recharge and the real price of sugarcane are constant, and the sugarcane production function holds fixed levels of inputs other than irrigation at the average sample values. We abstract also from possibilities of changes in technology, number of tubewells, and availability of other crop cultivation opportunities. Normalize by looking at a "representative" plot whose area A is the average sample plot size (in bighas). Let $F(x_k) = f((\bar{x}_j), x_k, \beta)$ be the production function of sugarcane as a function of irrigation on the plot, where inputs $j \neq k$ are fixed and input *k*, irrigation water, is the only variable input. Let *H* be the depth (in inches) of the underlying, flat-bottomed aquifer with vertical walls along the boundaries of the representative plot (so that sugarcane is the only activity that affects groundwater stock), *d* the depth (in inches) at which the water surface is at present, and *S* the groundwater stock (in bigha-inches). Therefore,

$$S = (H - d)A \tag{22}$$

Let R_v be the constant, annual natural recharge (in bigha-inches) and *R* the corresponding increment (in inches) of the water table. Let α be the proportion of irrigation water that recharges the aquifer. The average irrigation volumes in the sample and Simulation 3 (30-34.5 bigha-inches per bigha), along with approximate numbers $\alpha = 0.15, R = 9$ inches,[40] suggests that the water table will decrease at an annual rate of 1 ½ or more feet.

However, individual farmers' landholdings are very small relative to the size of the sugarcane belt and the underlying aquifer; an individual farmer's water use has negligible effect on groundwater stock, so that the farmer is expected, in period *t*, to maximize period *t* profit:

$$\pi_t = pF(x_{kt}) - c(S_t, y)x_{kt} \tag{23}$$

where *p* is sugarcane price, and $c(S_t, y)$ is the cost of extracting 1 bigha-inch of water as a function of the groundwater stock S_t, with unit electricity price *y* as a parameter. However a social planner would take into account the increase in pumping cost as the water table falls due to water extraction in period *t*. The unit social cost of extracting 1 bigha-inch at period *t* equals

$$c(S_t, y) + \delta(1-\alpha) \mid c'(S_t, y) \mid x_{kt+1} \tag{24}$$

40 See for example, R.S. Chaturvedi (1997)

the second term being the negative effect on pumping cost in period t+1 (δ is the time-discount factor, and c' is the derivative of the unit cost of extraction with respect to groundwater stock). *The question we ask is: Suppose y is the economic cost of generating, transmitting and providing 1 kwhr of electricity. What is the unit electricity price* $\tilde{y}$ *, marked up on y, such that an individual farmer's unit cost* $c(S_t, \tilde{y})$ *at this price equals the Eq.(24) unit social cost of water extraction*?

Ignoring pumping cost arising out of repair costs, the unit electricity price affects the pumping cost as follows. To extract 1 bigha-inch (or 20,558 kg) of water at a water depth of d_m metres requires work of approximately $205580 d_m$ joules. An ideal 1 kw (kilowatt) machine would perform this task in ($205{,}580 d_m / 3{,}600{,}000$) hours. A 1 kw pump with efficiency E (between 0.55 to 0.75 for electrical motors) would require $(205{,}580 d_m z / 3{,}600{,}000)$ hours, where z=(1/E). So if y is the price of 1 kwhr (kilowatt-hour) of electricity, using Eq.(22) and $d_m = (d / 39.37)$, we have

$$c(S, y) = \bar{c}zy(H - (S / A)),\ c'(S, y) = (-\bar{c}zy) / A \qquad (25)$$

where $\bar{c} = 205{,}580 / (3{,}600{,}000 \times 39.37)$. Using Eqs.(22), (24) and (25), we get

$$\tilde{y} = y[1 + \{(\delta(1-\alpha)x_{kt+1}) / Ad_t\}] \qquad (26)$$

where d_t is the water table depth (in inches) in period t. The economic cost of generating and transmitting 1 unit of electricity is arguably between Rupees 2.50 and 3 at present. At corresponding levels of extraction (available from Simulation 3), current water table depth of about 960 inches (80 feet), and a discount factor of 0.95, we get $\tilde{y} = 1.027y$. For instance, for an economic unit cost of power of Rupees 3, the markup is about Rupees 0.08.

The low, 2.7% markup in fact understates the effect of the negative externality from pumping. The simplest way to see this is to set up a social planner's problem of maximizing the discounted present value of profits from sugarcane, taking into account the costs of groundwater depletion. In the simplest model, we maximize the objective function $\sum_{t=0}^{\infty} \delta^t (pF(x_{kt}) - c(S_t, y)x_{kt})$ subject to an initial groundwater stock S_0 , and its evolution $S_{t+1} = S_t + R_v - (1-\alpha)x_{kt}$. Let $V(S_t)$ be the maximum value of discounted future profits evaluated in period t. Then the social planner will solve

$$V(S_t) = Max_{x_{kt}}[pF(x_{kt}) - c(S_t, y)x_{kt} + \delta V(S_{t+1})] \qquad (27)$$

subject to $S_{t+1} = S_t + R_v - (1-\alpha)x_{kt}$, where δ is the discount factor. Solving this, we get that along the optimal path,

$$pF'(x_{kt}) = c(S_t, y) + \delta[pF'(x_{kt+1}) - c(S_{t+1}, y) - (1-\alpha)c'(S_{t+1}, y)x_{kt+1}] \quad (28)$$

Comparing Eq.(24) with the right hand of Eq.(28), we see that the latter has an additional term, $\delta(pF'(x_{kt+1}) - c(S_{t+1}, y))$, corresponding to foregone future profits as a consequence of incremental water extraction today. While this term evaluates to zero for a farmer who undertakes period-by-period profit maximization, it is positive along the socially optimal path. We are interested in whether this results in $\tilde{y}$ being a substantially higher markup on *y* than the 2.7% obtained on evaluating Eq.(26).

The markup depends on where the sugarcane economy is on the optimal path. Since the model is too simplistic, we do not undertake the full-blown exercise of solving for the optimal path. Since the optimal path in this model converges to an equilibrium or steady state $(\bar{S}, \bar{x}_k)$ in which rates of water extraction and recharge (natural and backflow from irrigation) are equal; (i.e., where water extraction is sustainable), we calculate the markup in the steady state. Substituting steady state values for groundwater stock and water extraction in Eq.(28) and rearranging using Eqs.(22) and (25), we get

$$\tilde{y} = y\,[\,1 + \{\,(\delta(1-\alpha)\bar{x}_k)/(A\bar{d}(1-\delta))\,\}\,] \quad (29)$$

where $\bar{d}$ is the steady state depth of the water table. A principal shortcoming of this simple model is that the steady-state rate of water extraction corresponds to about 11 bigha-inches per bigha, which is less than half of what is agronomically sensible for sugarcane. A better model would therefore incorporate the possibility of crop switching. Since such a switch would necessarily be to a less irrigation intensive activity, the steady state groundwater stock for the present model is an upper bound for what would be optimal in a more sophisticated model.

We find that the minimum, steady state water table depth (under conservative assumptions about aquifer depth, pump efficiency etc.) is about 107 feet. Evaluating Eq.(29) under this assumption, we get $\tilde{y} = 1.148y$. Thus the required markup of 14.8% is substantially larger than that suggested by evaluating Eq.(26); if *y*=Rupees 3, the markup is Rupees 0.44.

We conclude that power supply reform should incorporate a markup of about 15% on the economic cost of providing electricity. Finally, note that a steady state water table depth of 107 feet suggests that the “surplus” 27 feet be mined sensibly while converging to a sustainable policy.

6. Conclusions and Policy Recommendations

The principal crops of North India include two water intensive crops – sugarcane and paddy. This paper attempts to understand the institutions that govern the water economy in sugarcane production in this region. In the context of low and decreasing water tables, policy should focus on two objectives: first, the water used in agriculture should maximize yields; for this it is necessary that water be allocated efficiently across the sugarcane producing region. Second, that water usage should be at levels that are sustainable.

Our sample shows that irrigation volumes show considerable variation across plots. By estimating a production function, we discover that the marginal product of water is significantly higher than the water prices on the plots, evidence of widespread water rationing. The MPWs are also significantly different across plots. But Simulation 1 confirms that the negative effect on yield from this is very small; the close-to-efficient water allocation is in sharp contrast to much of the literature which most often finds in favor of inefficiency. We infer the existence of village level social norms of water sharing that result in efficient water allocation. Simulation 2 shows that water allocation in the absence of such a social contract would result in an 18% decrease in average yield. While the social contract successfully avoids water misallocation arising from water rationing, the rationing has other negative effects: limited power availability leads to overinvestment is tubewells and pump horsepower to enable pumping up water as quickly as possible.

In addition to restricting water supply below demand, the *erratic* nature of the power supply introduces considerable uncertainty in the water availability and irrigation timing. This paper does not address the effect of erratic timing of irrigations on yields. Even so, Simulation 3 shows that in a setting of *reliable* power supply, yields increase by 4% at irrigation levels comparable to those in the sample, and by up to 9% if the entire water demand can be met with the help of *adequate* power supply. Yield increases come at the cost of heavier water use, even at fairly high electricity prices. The higher yields are sufficient to pay for the power tariffs necessary to incentivize the power provider to supply reliable and adequate power.

While a rationalized power policy can be of great help in maximizing "crop per drop", it cannot by itself address the problem of sustainability, at least at reasonable power prices[41]. At such prices, irrigation volumes are between 8.5 and 12.5 percent higher than in the sample. This is not hard to understand, given that water consumption itself is not priced. We must also bear in mind the way in which agricultural belts develop in sugarcane, paddy and other crops. This reflects great economies of agglomeration, and well-oiled supply chains from farmer to factory to retail markets. So for a water intensive crop, a relentless thirst for water is not unexpected. In the backdrop of rapid growth, traditional rights of water use may prove inadequate to the task of governing water use in a sustainable fashion, as individual farmers ignore the negative externality

[41] Prices somewhere between Rupees 2 and Rupees 3 per kw-hour should cover the economic cost of providing power. While Simulation 3 shows that sugarcane cultivation is quite profitable even at substantially higher rates in the study area, this may not be true for all parts of the sugarcane belt.

of their water extraction on others. None of the standard suggestions such as pricing of water, Pigovian taxes etc. have been implemented anywhere; more research is required to understand what institutions will be attentive to the shadow price of water use[42]. We suggest that a markup of about 15% on the economic cost of providing electricity may result in farmers' water extraction activity to be in line with what is socially optimal. The resulting decrease in farmers' incomes can in principle be compensated through lump sum transfers.

Implementability is a serious concern for changing the power regime. The financial condition and rules of operation of traditional power providers (SEBs) are such that these providers lack credibility. If they were to announce a radically different power pricing scheme in return for reliable power supply, announcements on reliability would, likewise, probably lack credibility. For one thing, North India faces power shortage at present. The electricity charges for industry and for households are far higher than estimates of the economic cost of producing and delivering power efficiently. It is debatable whether the power provider will sell adequate and reliable electricity to farmers at unit prices below what it can charge power-constrained industries and households. Deeper structural changes, such as allowing competition between multiple power providers may work but this requires a huge regime change. Nevertheless, our paper demonstrates that the "fundamentals" of the sugarcane belt, on questions of yields, yield responses to water allocation, and profitability are at levels that can respond favorably to such regime changes.

The present paper represents only a first step at addressing the objectives herein, as its focus is on a single village. A larger study would be better able to control confounding factors, and result in better estimates of a sugarcane production function and simulations that are more finely varied. Nevertheless, the narrow focus on a single village brings out elements and institutions common to the sugarcane belt as a whole; these insights can be used in a larger study.

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[42] See Shah, Zilberman and Chakravorty (1993) for a discussion of first and second-best solutions to the externality problem related to groundwater use.

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APPENDIX A: List of Variables Collected

A.1. Plot-Specific

A.1.1. Irrigation:

Date of Irrigation 'i', where i=1,2,…
Desired date of for providing i^{th} irrigation
Reason for being unable to irrigate on desired date
Source of irrigation (own tubewell, shared tubewell or purchased water)
Whether the field was flooded on i^{th} irrigation (yes or no)
The depth of water in inches on the i^{th} irrigation
Number of hours on i^{th} irrigation taken to flood the field to reported number of inches
Terms of irrigation when source is a shared tubewell
Terms of purchase where source is purchased water
Distance of plot from tubewell

A.1.2. Soils

pH
Electrical conductivity
Organic carbonate (%)
Texture
Iron (parts per million)
Copper (parts per million)
Zinc (parts per million)
Potassium (parts per million)

A.1.3. Seed, Fertilizer, Manure, Insecticides and Pesticides

Seed (for fresh-sown) quantity
Number of applications of fertilizer
Amount applied (by type of fertilizer—urea, DAP, superphosphate etc) on 1^{st} application
Cost of input on 1^{st} application
Amount applied (by type of fertilizer—urea, DAP, superphosphate etc) on 2^{st} application
Cost of input on 2^{nd} application etc.
Similarly,
Number of applications of pesticide/weedicide etc
Amount applied (by type of pesticide/weedicide etc) on each application
Cost of input at each application

A.1.4. Labor

By activity: (which include sowing, weeding, digging, irrigating, fertilizer application, providing support to sugarcane stalks, harvesting)
Number of persons engaged
broken down by: hired (casual), hired (permanent), family, exchange labor, piece rate
Number of hours of labor
broken down by: hired (casual), hired (permanent), family, exchange labor, piece rate
Payment for hired labor
broken down by cash and kind components

A.1.5. Tractor and oxen hours:

By activity:

Number of hours of tractor used on plot

broken down by own, hired, exchange, piece-rate

Payment for hired tractor use

broken down by cash and kind components

Number of oxen hours used on plot broken down by own, hired, exchange, piece-rate

A.1.6. Area

Area under sugarcane by variety and type

Terms of lease (farmer-cultivated, leased-in, leased-out)

Area under other crops

A.1.7. Output:

By variety and plot (rattoon versus fresh sown, early variety and general variety)

Date of harvest

Quantity harvested

Quantity sold to mill

Quantity sold to other private purchasers

Price obtained from private buyer

A.2. Tubewell-Specific

Type of tubewell installed (submersible versus nonsubmersible)

Name of owners (both own and joint)

Year of installation

Depth of boring, filter and pump

Depth of water level

Horsepower of pump

Cost of installation

Number of times in previous year repairs were effected

Major reasons repair was necessitated

Amount spent on repair each time

Amount spent on electricity over 12 months

Tubewell history (particulars of why deepening, tubewell/pump replacement was necessitated)

Discharge (amount taken to fill 150-litre tanks, average of two measurement)

A.3. Farm household-specific

Demographic composition of farm household

Education level of adult members of the household

Farm assets

Other assets

APPENDIX B: Technical Details

B.1. Proofs of Propositions

Proof (sketch) of Proposition 1.

Farmer *i*'s water demand comes out of the optimization problem: Choose nonnegative x_{ik} to Maximize $u(pf((x_{ij}), x_{ik}, \beta) - q_{ik}x_{ik})$. Since $u' > 0$, we may apply u^{-1} to the maximand. The first-order condition for an interior max is solved by the amount x_{ik}^{*}, defined in Eq.(2) of the text.

So, once the choices of inputs other than water, $(x_{sj}),(x_{ij})$ have been made, and a water volume w_t is realized, the optimization problem for farmer *s* is:

Choose nonnegative amounts x_{sk}, x_{ik} to maximize

$u(pf((x_{sj}), x_{sk}, \beta) - c_t x_{sk} + (q_{ik} - c_t)x_{ik})$, subject to $x_{sk} + x_{ik} \le w_t$ and $x_{ik} \le x_{ik}^{*}$. Applying u^{-1} to the maximand, form the Lagrangean function L =

$$pf((x_{sj}), x_{sk}, \beta) + q_{ik}x_{ik} - c_t(x_{sk} + x_{ik}) + \lambda_s x_{sk} + \lambda_i x_{ik} + \lambda(x_{ik}^{*} - x_{ik}) + \mu(w_t - x_{sk} - x_{ik}),$$

we get the Kuhn-Tucker necessary conditions for an optimum:

$$pf_k((x_{sj}), x_{sk}, \beta) - c_t + \lambda_s - \mu = 0 \qquad \text{(B.1.1)}$$

$$q_{ik} - c_t + \lambda_i - \mu - \lambda = 0 \qquad \text{(B.1.2)}$$

$$\lambda_s x_{sk} = 0 \qquad \text{(B.1.3)}$$

$$\lambda_i x_{ik} = 0 \qquad \text{(B.1.4)}$$

$$\lambda(x_{ik}^{*} - x_{ik}) = 0 \qquad \text{(B.1.5)}$$

$$\mu(w_t - x_{sk} - x_{ik}) = 0 \qquad \text{(B.1.6)}$$

(B.1.3) to (B.1.6) hold with complementary slackness. Suppose $x_{ik} = 0$, so $\lambda = 0, \lambda_i \ge 0$. Substituting (B.1.2) in (B.1.1) we get $pf_k((x_{sj}), x_{sk}, \beta) - \lambda_i = q_{ik}$.

So, the solution to this, x_{sk}, is less than or equal to x_{sk}^* (as defined in Eq.(1) of the text). Moreover, it must be that $w_t = x_{sk}$, for if instead we have $w_t > x_{sk}$, then by (B.1.6), $\mu = 0$. Plugging this in (B.1.2), that equation becomes $q_{ik} - c_t + \lambda_i = 0$. But since $q_{ik} - c_t > 0, \lambda_i \geq 0$, we have a contradiction. Thus we have that $w_t \leq x_{sk}^*$ implies that the water allocation is $(x_{sk}, x_{ik}) = (w_t, 0)$. The rest of the specification in Proposition 1 is proved with similar arguments.

Proof of Proposition 2.

Consider the function $F : [0, \overline{w}_t] \times [0, \overline{w}_t] \rightarrow [0, \overline{w}_t] \times [0, \overline{w}_t]$ defined by:

$F(x_{sk}, x_{ik}) = (x_{sk}^*((x_{sj})(x_{ik})), x_{ik}^*((x_{ij})(x_{sk})))$. That is, suppose the social contract described under Assumption 1A (Section IV) governs water allocation using the parameters x_{sk}, x_{ik}. $(x_{sj})(x_{ik})$ is the vector of inputs j, $j \neq k$, that solves Eq.(10) when *i*'s water parameter is x_{ik}. $x_{sk}^*((x_{sj})(x_{ik}))$ is the irrigation volume that solves Eq.(1) if the vector of other inputs equals (x_{sj}). The function $(x_{sj})(x_{ik})$ is continuous by the Theorem of the Maximum. The function $x_{sk}^*(x_{sj})$ is continuous by an application of the Implicit Function Theorem on Eq.(1). So, their composition, $x_{sk}^*((x_{sj})(x_{ik}))$, is continuous. The second component of *F*, $x_{ik}^*((x_{ij})(x_{sk}))$ is similarly defined, for farmer *i*, using Eq.(13) in place of Eq.(10) and Eq.(2) in place of Eq.(1). This component is continuous by the same argument as for the first component. Therefore, *F* is a continuous function on a compact set. By Brouwer's Fixed Point Theorem, there exists a fixed point (x_{sk}^*, x_{ik}^*) Using this x_{sk}^* and x_{ik}^* to define the water sharing in the social contract, solutions (x_{sj}) to Eq.(10) and (x_{ij}) to Eq.(13) will also solve Eq.(10) and Eq.(13) simultaneously. These solutions, along with water allocations X_{sk}, X_{ik} defined using x_{sk}^* and x_{ik}^*, therefore constitute an equilibrium.

B.2. Confidence Intervals for Marginal Product of Water

Let the estimated marginal product of water on plot *i* be $f_k(x_i, \hat{\beta})$ (see Section IV). Since $\hat{\beta}$ is consistent, for a large enough sample we can take a first-order Taylor approximation of the marginal product:

$$f_k(x_i,\hat{\beta}) - f_k(x_i,\beta) \approx D_\beta f_k(x_i,\beta)^T(\hat{\beta}-\beta) \quad \text{(B.2.1)}$$

where $D_\beta f_k(x_i,\beta)^T$ is the transpose of the gradient of the function f_k (with respect to the parameter vector β), evaluated at (x_i,β). Let $V = Cov(\hat{\beta})/n$, or a consistent estimator of it. If $\hat{\beta}$ is asymptotically normal, we have

$$\sqrt{n}(\hat{\beta}-\beta) \xrightarrow{d} N(0,V) \quad \text{(B.2.2)}$$

From Eq.(C.1) and (C.2) we get

$$\sqrt{n}(f_k(x_i,\hat{\beta}) - f_k(x_i,\beta)) \xrightarrow{d} N(0, D_\beta f_k(x_i,\beta)^T V\, D_\beta f_k(x_i,\beta)) \quad \text{(B.2.3)}$$

Or, in simpler notation,

$$\sqrt{n}(\hat{m}_{w_i} - m_{w_i}) \xrightarrow{d} N(0,\sigma^2_{w_i}) \quad \text{(B.2.4)}$$

Replace β with $\hat{\beta}$ on the RHS in Eq.(B.2.3), and call the resulting variance $\hat{\sigma}^2_{w_i}$. Using this and Eq.(B.2.4), we have

$$\frac{(\hat{m}_{w_i} - m_{w_i})}{\hat{\sigma}_{w_i}/\sqrt{n}} \xrightarrow{d} N(0,1)$$

(B.2.5)

From this we get the 95% confidence interval

$$\Pr(m_{w_i} \in (\hat{m}_{w_i} - \frac{1.96\hat{\sigma}_{w_i}}{\sqrt{n}}, \hat{m}_{w_i} + \frac{1.96\hat{\sigma}_{w_i}}{\sqrt{n}})) = 0.95 \quad \text{(B.2.6)}$$

B.3. Estimating Marginal Cost of Water Extraction from a Tubewell

Farmers pay a lump sum annual electricity charge for running a tubewell. So the marginal cost of water extraction includes only those maintenance costs that depend on water output. Maintenance costs are essentially costs of repairing the pump set in the event of a breakdown. While the frequency of breakdowns is high due to power surges, what is germane here is that the number of breakdowns may depend on the number of hours that the tubewell operates. It also depends on whether the machine is a submersible (fewer breakdowns) or a nonsubmersible. We assume that the number of breakdowns follows a *Poisson Process* (see Ross (1997)) with parameters μ_1, μ_2

for submersibles and non-submersibles respectively. Let J_1, J_2 be the sets of submersibles and nonsubmersibles respectively. So, for *submersible* tubewell *j*, the probability that the number of breakdowns *N* equals n_j if it runs for time h_j,

$$\Pr(N(h_j) - N(0) = n_j) = e^{-\mu_1 h_j} \frac{(\mu_1 h_j)^{n_j}}{n_j!}$$

(B.3.1)

Using Eq.(B.3.1) and data on total number of breakdowns and number of running hours for each submersible tubewell, we set up a likelihood function and get an estimate $\hat{\mu}_1$ for the Poisson parameter.

Since the likelihood of the submersible sample $(h_j, n_j)_{j \in J_1}$ is

$$e^{-\mu_1 \sum_{j \in J_1} h_j} . \mu_1^{\sum_{j \in J_1} n_j} . \Pi_{j \in J_1} \left(\frac{h_j^{n_j}}{n_j!} \right) \qquad \text{(B.3.2)}$$

the first order condition yields the maximum likelihood estimate

$$\hat{\mu}_1 = \frac{\sum_{j \in J_1} n_j}{\sum_{j \in J_1} h_j} \qquad \text{(B.3.3)}$$

which is just the total (or average) number of submersible breakdowns in the data divided by the total (or average) number of hours that submersibles in the data ran for. A similar exercise yields the Poisson parameter estimate for nonsubmersibles.

Suppose that it takes time t_j to extract 1 unit (bigha-inch) of water using submersible tubewell *j*. Then, the expected number of breakdowns in this time,

$$E(N(t_j)) = \hat{\mu}_1 t_j \qquad \text{(B.3.4)}$$

Our estimated marginal cost of water extraction from this tubewell is the above number times the average cost of repair.

B.4. Aggregating General and Early Variety Yields.

Plots in the data set are either all covered with a rattoon crop, or fresh sown sugarcane. Rattoon crops can differ by year of rattoon with the oldest crop being three years. In the surveyed village, two varieties of sugarcane are grown. These are early and general variety and they differ slightly by sugar content and therefore by price. The early variety with a higher sugar content commands a 5% higher price than the general variety. Some plots have sown on them two varieties of sugarcane while others have only one variety. Out of a total of 326 plots, 33 plots grow early variety and 203 plots grow general variety of sugarcane. On the remaining 91 plots, both varieties are grown.

For plots with one variety of sugarcane 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, while for mono variety plots, the average computed before was considered.

TABLES

Table 1. Summary statistics on water use and yields

1.1. Water transactions on single-owner and joint-owner tubewells

1.2. Characteristics of submersible and non-submersible tubewells.

	Submersible tubewells	Non-submersible tubewells
Average electricity costs (Rs.) per year	9665	9012
Average number of times repairs were effected	1.5	3.2
Average maintenance costs (Rs.) per year	3356	6151
Average time taken to irrigate one bigha	90	120

1.3. Irrigation details, by category of plot

	Plots with Own Tubewell	Plots with Jointly-owned Tubewell	Plots using purchased water
Number of plots	117	123	87
Average area per plot (bighas)	11.7	5.7	4.7
Mean number of irrigations	10.7	9.6	8.0
% plots receiving 5 irrigations before 31 July (start of monsoon)	73	61	37

1.4. Yields of sugarcane, by category of plot (quintals per bigha)

	Plots with own tubewell	Plots with jointly-owned tubewell	Plots with purchased water
Overall	60.4	59.8	53.4
Rattoon yields	68	69	60
Fresh-sown yields	48	47	45

1.5. Yields, by soil type and source of irrigation (quintals per bigha)

	Sandy loam soils	Loam soils
Category I	57	57
Category II	60	57
Category III	52	58

Table 2: Summary Statistics of Other Inputs and Output Variables (326 observations)

Variable	Mean	Standard Deviation	Min	Max
Output (quintals)	443.22	430.1632	30	4000
Plot Area (bighas)	7.49	6.207829	1	50
Labor (hours)	1302.23	1189.119	178	9190
Manure (quintals)	116.19	228.4198	neg	2520
Fertilizers (value)	1704.15	1686.361	81	10915
Tractor(hours)	7.91	22.15217	neg	200
Oxen(hours)	86.37	99.61757	neg	568
Irrigation (bigha-inches)	222.52	208.5923	5.2	1330

Table 3. Cobb-Douglas Production Function Estimates (Variables in logs)

Output	Coefficient	Standard Error	t-ratio
Plot Area	0.7422***	0.0444	16.71
Labor	0.0762***	0.0287	2.65
Manure	0.0014	0.0060	0.23
Fertilizers	- 0.0280	0.0177	-1.58
Tractor	0.0905***	0.0176	5.14
Oxen	0.1254***	0.0177	7.07
Irrigation	0.0643***	0.0246	2.61
Crop Dummy (1=rattoon)	0.4863***	0.0416	11.70
Farmer Dummies	** and ***		
Constant	2.9962***	0.1749	17.13

Other information on the Cobb-Douglas Estimation:
Number of Observations: 326; F(16,309) = 396.47; Prob > F = 0.0000; R-squared=0.9536; Adjusted R-squared=0.9511

Table 4A. Estimates for Value of Marginal Product of Water (MPW) (incremental rupees per incremental bigha-inch), with 95% Confidence Intervals; Water Price (rupees per bigha-inch)

Variable	Plot Type (irrigated by own /joint TW/bought water)	Observations	Mean	Std. Dev.	Min	Max
MPW	All	326	16.63*	25.753	4.455	91.902
Upper Conf	All	326	16.67	25.800	4.466	92.086
Lower Conf	All	326	16.60	25.705	4.444	91.729
Water Price	All	326	6.53	2.12	2.77	13.64

*****_We dropped two outliers which reduced the mean value of marginal product of water to Rs.14.9 per bigha-inch increase in irrigation volume. There was a substantial decline in standard deviation to 9.26, thus re-enforcing the fact that the marginal products were fairly closely distributed._

Table 4B. Mean Marginal Value Product of Water by Plot Type'

Variable	Plot Type	# of plots	Mean
MPW	Own TW	117	11.872
Uppr Conf	Own TW	117	11.899
Lowr Conf	Own TW	117	11.844
MPW	Joint TW	122	19.916
Uppr Conf	Joint TW	122	19.960
Lowr Conf	Joint TW	122	19.873
MPW	Bought	86	18.434
Uppr Conf	Bought	86	18.476
Lowr Conf	Bought	86	18.392

Table 5. Simulation 1: What would be profits and output from the sample plots if the total observed water from each tubewell in the sample is allocation efficiently across the plots that are serviced by that tubewell?

Plot Category	Sample Yield (Average)	Simulated Change (yield)	Simulated Change (value)
All Plots	58.22	+0.18	+18.36
Plots with Single-Owner TW	59.17	-0.04	-4.08
Plots with Joint-Owner TW	58.43	+0.24	+24.48
Plots that bought water	53.58	+1.0	+102.0

Table 6. Simulation 2: What would outputs be if the total observed water *from each tubewell* is allocated to the plots it services so as to enable the tubewell owner to maximize profits?

Plot Category	Sample Yield (per bigha)	Simulated Yield (per bigha)
All Plots*	57.51	48.14
Plots with Single-Owner TW	58.41	59.12
Plots with Joint-Owner TW	60.07	60.95
Plots that bought water	53.74	16.33

Table 7. Simulation 3: Effect of Unit Power Price on Yields, Irrigation Volumes, Profits

Power Price	Yield	Profits	Irrigation Volume	Power Revenue
(sample: zero unit price)	58.22	2490.56* (2220.56)	30.02	270.31* (540.31)
1.8	63.4338	2636.1804	34.5176	384.6204
1.9	63.3836	2616.2357	34.1385	401.7316
2	63.3360	2596.4366	33.7963	418.8289
2.1	63.2907	2576.7693	33.4861	435.9144
2.2	63.2476	2557.2219	33.2035	452.9903
2.3	63.1195	2533.6659	32.9956	471.0904
2.4	63.0813	2514.2502	32.7635	488.3062
2.5	62.9887	2491.9996	32.6012	506.6464
2.6	62.9545	2472.6854	32.4072	523.9775
2.7	62.9216	2453.4454	32.2274	541.3042
2.8	62.8899	2434.2745	32.0603	558.6274
2.9	62.8594	2415.1678	31.9047	575.9475
3	62.8299	2396.1209	31.7593	593.2650
3.1	62.8014	2377.1302	31.6232	610.5804
3.2	62.7738	2358.1919	31.4957	627.8941
3.3	62.4314	2322.9822	31.1251	642.1855
3.4	62.4080	2304.1724	31.0277	659.6200
3.5	62.3852	2285.4019	30.9359	677.0532
3.6	61.6417	2231.5214	30.5945	690.0775
3.7	61.6243	2212.8377	30.5327	707.7468
3.8	60.9425	2162.8572	30.4896	725.9292
3.9	60.9292	2144.1180	30.4425	743.9014
4	60.9163	2125.3980	30.3977	761.8723
4.1	60.9036	2106.6964	30.3551	779.8420
4.2	60.8913	2088.0123	30.3145	797.8106
4.3	60.8793	2069.3449	30.2757	815.7783
4.4	60.8676	2050.6933	30.2386	833.7451
4.5	60.8562	2032.0570	30.2032	851.7112

Units: Power Price: Rupees per kilowatt hour; Yield: Quintals per bigha; Profits: Rupees per bigha Irrigation Volume: Bigha Inches (per bigha); Power Revenue: Rupees per bigha

* This simulation was conducted over 163 plots to account for only those tubewells which served buyers' plots.

Figures

Figure 1: Policy Simulation: Yields and Irrigation

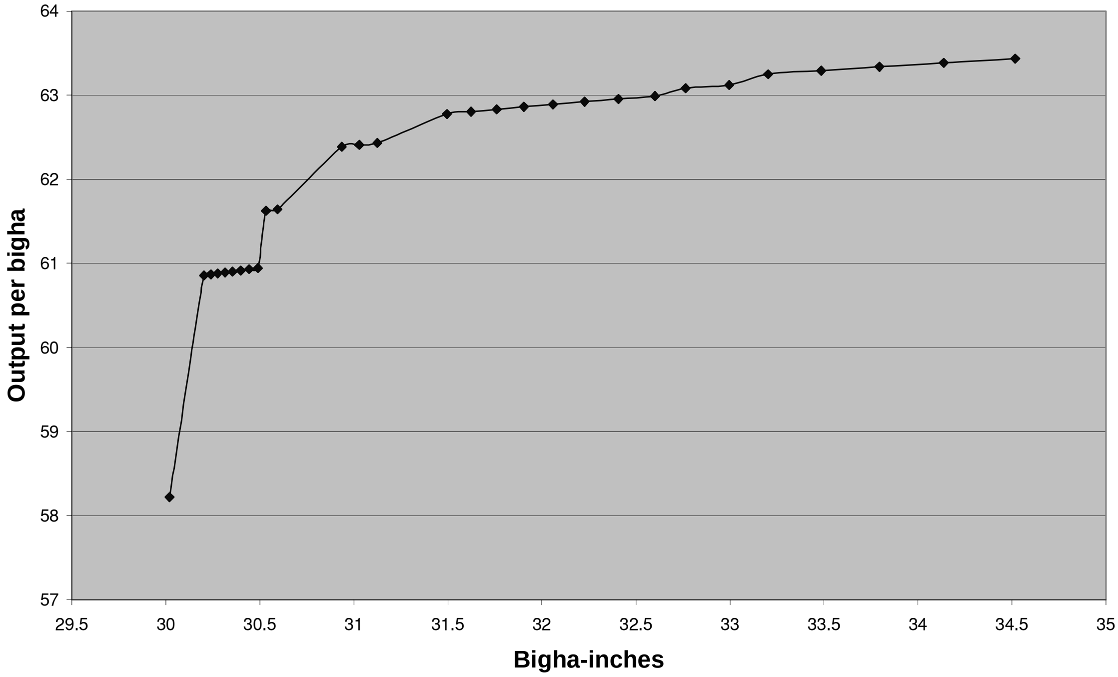

Figure 2: Policy Simulation: Electricity Price, Farm Profits, Power Revenues