The Efficiency of Rationing: Agricultural Power Subsidies, Power Supply and Groundwater Depletion in Rajasthan*

[PRELIMINARY AND INCOMPLETE; DO NOT CITE]

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Abstract

Energy subsidies are popular around the world despite being inefficient on their face. Rationing energy may increase efficiency in the second-best regime given these subsidies. We study the rationing of electricity for farmers in Rajasthan, India, where power is a lifeline that farmers use to pump up groundwater for irrigation. Power rationing binds on farmers, both on the intensive margin (hours of supply are limited to six per day) and on the extensive margin (many farmers are not allowed on the grid). The rationing policy and groundwater extraction costs together act as a shadow price on groundwater. We use this equivalence to estimate the efficiency of the rationed power supply. Preliminary estimates suggest that efficient rationing may be even stricter than observed.

1 Introduction

Telangana was born as a new state in 2014, carved out of Andhra Pradesh in south-central India. The Telangana government, eager to distinguish itself as a champion of farmers, in

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2017 started and in 2018 broadly expanded a new policy: free power for farmers, not only for a rationed block of hours, as Andhra Pradesh had given before, but for all twenty-four hours in a day.

> Telangana chief minister K Chandrasekhar Rao described the 24 × 7 agriculture power supply as a New Year's gift for the farmers of the state.
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> "Though certain states are supplying power to farmers free of cost, it is only for a few hours; and some states are giving 24-hour power supply but for a price. Telangana is the only state which is supplying power to farmers round the clock free of cost" (Apparasu, January 1st, 2018)

Farmers spurned the gift. Yerram Anjireddy, a farmer, said "Motors will pull out ground water and bore wells will dry out. We are completely dependent on bore wells for farming. The 24-hour power supply is a big threat to our future." (BBC News, 2017) Residents of Gorantala village passed a resolution urging the Government to restrict power supply to nine hours to conserve water (Dayashankar, July 22nd, 2017). Telangana Pradesh Congress Committee farmers' cell president M Kodanda Reddy asked "What is the point in giving more power, when there is no groundwater?" (Apparasu, January 1st, 2018). Amid widespread, grassroots protests, the government began scaling back the unrestricted power regime less than a month after it was launched (Deccan Chronicle, January 28th, 2018).

The farmers may be right. With a low or non-existent price of power, and no price at all on groundwater, rationing power is the only way to conserve a common resource. The world is awash in subsidies to energy prices (Davis, 2014), which are widely scorned, for inflating fossil fuel usage, polluting the air and straining government budgets. But in many subsidized energy markets, price is not the only factor in efficiency, since the state also controls the supply of energy. The efficiency of energy policy in these cases depends on the whole supply regime, including both pricing and rules for rationing and allocation.

This paper considers the effects of energy subsidies in a supply regime that also includes endogenous rationing. The context is electricity use for groundwater-fed irrigation in Rajasthan, India. Rajasthan is a largely arid or semi-arid state and much agriculture there is possible only with groundwater irrigation. The marginal price of electricity for agriculture, set by the state and supplied by a state distribution company, is nineteen percent of the private marginal cost of supply. The power subsidy, viewed as a lifeline for marginal farmers, is politically sacrosanct.

We collect primary data to study the efficiency effects of this rationing regime. We survey grid-connected farmers and a sample of farmers not connected to the grid regarding their electricity usage and costs. Our survey also covers agricultural decision-making in detail, measuring cropping and irrigation choices, inputs, outputs, and profits.

Our empirical goal is to estimate the efficiency of rationing. We cannot estimate this directly, since the rationing policy is uniform across the state, so there is no variation in rationing from which to estimate its effects on farmer profits or other outcomes. Our empirical approach is therefore to use variation in water scarcity to infer the effects of rationing, since rationing and water scarcity both act in the same way. In particular, the amount of water a farmer can extract is increasing in hours of supply and inversely proportional to water depth. Therefore, the effects of relaxing the rationing regime (increasing hours) and water scarcity (reducing depth) are equivalent. We use this fact and hedonic profit estimates to calculate the implied change in social surplus from the utility marginally relaxing the rationing regime.

The paper has three main findings. First, rationing binds. Farmers are using nearly all of the energy they could possibly use, under a supply regime that offers only six hours per day of supply during the peak growing season. Moreover, the supply of connections to the power grid is limited on the extensive margin, and this binds on farmers seeking new connections. There is a waiting list in Rajasthan with more than 300,000 farmers seeking grid connections, about a quarter of the 1.1 million that have a connection already, and a typical wait of seven years or more. Farmers that do not have grid-connected pumps have smaller landholdings and agricultural revenues than those who do have pumps, and farmers without pumps farm their land less intensively.

Second, water scarcity decreases farmer profits. We run Ricardian regressions of farmer profits on water scarcity, measured as the depth to groundwater, and exogenous farmer- and plot-level controls. This method is common in the climate literature to measure longer-term effects of climate, as opposed to short-term effects of weather shocks (Mendelsohn, Nordhaus and Shaw, 1994; Mendelsohn, Dinar and Williams, 2006; Schlenker, Hanemann and Fisher, 2005). We find that farmers facing greater water scarcity sink deeper wells, are more likely to grow water-hardy crops and make investments in water-conserving irrigation technology, and that, with these investments, there is no effect of water scarcity on yields. However, water scarcity still decreases profits. In our preferred specification, a one standard deviation increase in depth to groundwater reduces profits by USD 71 per season, or 27% of the mean profit of USD 265 per season (including the imputed value of own consumption of agricultural output). The difference between profit and yield results suggests shows the incompleteness of adaptation when measure in economic, as opposed to physical, terms; adapting is costly, even if it is able to sustain a certain quantity of output.

Third, tentatively, the optimal rationing regime may be even stricter than that observed. We calculate the marginal effect of relaxing the rationing regime from six hours a day to seven. The marginal benefits, estimated to be USD 24 per Ha per season, and marginal private cost, estimated to be INR 1240 per Ha (USD 21) per season, are roughly equal. (The marginal benefit gain is equal to nine percent of the average farmer profits in the dry season, USD 265). Therefore, despite the large effect of water scarcity on profits, the rationing regime is roughly efficient, when accounting for only the price of power.

Since water has no price of its own, there is also a dynamic opportunity cost of water extraction, which we have omitted above. Our finding therefore suggests that optimal rationing, accounting for the price of water, would be even stricter than observed. We also do not account for fixed costs such as greater well investment that do not appear in farmer variable profits, which would also favor stricter rationing.

The main contribution of this paper is to measure the efficiency of quantity restrictions in an energy supply regime that includes distortionary price and quantity instruments. We document, what we believe is new, that rationing binds on farmers on both the extensive and intensive margins. We use the equivalence between rationing (which does not vary, as it is a uniform policy) and water scarcity (which does vary across space) to recover Ricardian estimates of the long-run profit change due to a relaxation in rationing.

The larger point is that the persistence of inefficient subsidies is less puzzling when viewed as part of a joint rationing regime. One argument for the persistence of subsidies is on equity grounds: if the government cannot reliably make lump-sum transfers (Niehaus and Sukhtankar, 2013), then perhaps subsidizing energy helps the poor and provides insurance against a volatile part of household budgets. Or, on agency grounds: if the government is not unitary, public companies may maximize their profits by extracting subsidies but providing poor quality (McRae, 2015). Our paper suggests a complementary explanation for energy subsidies, which is that their efficiency cost is mitigated by endogeneously rationed supply.

Our analysis can speak to the optimal level of rationing but not the efficiency of rationing vis a vis a regime with marginal pricing of both power and water. In the presence of other market failures, such as credit constraints, the relative efficiency of these regimes is not clear. Donna and Espín-Sánchez (2016) study the reform of a water market into a quota system in Spain, and find that quotas (rationing) are more efficient than prices in the presence of liquidity constraints. We do not directly model or consider the primal market failures that may justify subsidies in the first place, but study the effects of rationing taking the subsidy regime as given. Data on farmer profits and water scarcity allow us to estimate the effects of rationing despite a lack of variation in the rationing regime itself.

The paper proceeds as follows. Section 2 introduces the context, the rationing policy and the data. Section 3 shows that rationing binds. Section 4 estimates the effect of water scarcity on profits, and uses this relationship to calculate the marginal surplus from relaxing the electricity rationing regime. We conclude by discussing what the analysis omits and paths for policy reform.

2 Context and Data

Free power for farmers came about due to technological change and politics. The technological change was the Green Revolution, in which farmers adopted higher-yielding varieties of crops that were more dependent on intermediate inputs, such as fertilizer and water, than traditional varieties. The political change was Indian states recognising this complementarity and using cheap or free electricity as a political handout in the 1970s and 1980s (See Badiani, Jessoe and Plant (2012) for a concise history). These policies were initially not very costly, since rural areas were largely unelectrified, but became more costly over time in both environmental and fiscal terms. This section describes agricultural electricity policy in Rajasthan and its consequences in these domains.

(a) Agricultural electricity subsidies

Rajasthan, like many Indian states, offers very large subsidies for the agricultural use of electricity. The agricultural electricity tariff in Rajasthan is Rs 0.9 per kWh (1.5 US cents per kWh, at Rs 60 per USD), against a power purchase cost of Rs 4.75 per kWh (USD 0.08) and a distribution cost of Rs 7.23 per kWh (USD 0.12) or higher. Thus the marginal price of electricity is 19% of the marginal cost of energy and 12% of the private cost of distribution.

These tariff subsidies are on the margin and can only be reliably applied if consumers are metered. Farmers who are not metered are billed on a flat rate which is subsidized to a similar degree, based on assumed levels of farmer consumption over the year. Of the survey sample, 83% of farmers are on the metered tariff and 71% report a working meter.

While the subsidies for agricultural electricity in Rajasthan may appear extreme, they are not atypical and are less generous than in several other prominent agricultural states of India. In large agricultural states including Punjab, Tamil Nadu, Maharashtra, Andhra Pradesh, and Telangana power for agricultural consumers is free and typically unmetered.

(b) Groundwater depletion

Farmers use electricity to power electric pumps that lift groundwater to irrigate their crops. The yield, in volume of water, depends on the depth and other characteristics of the well and the power input and efficiency of the pump.

Northwestern India has perhaps the worst groundwater depletion in the world. Water usage is not directly metered but both well-based and satellite-based measurements suggest a high rate of groundwater extraction and reservoir depletion. The Central Groundwater Board of India has an extensive network of monitoring wells and estimates that Rajasthan is extracting groundwater at 137% of the rate that can naturally be recharged (Central

Groundwater Board, 2013-2014).[1] This groundwater depletion is on such a scale that it is apparent to satellites that measure changes in the mass of the earth. Figure 1 shows the change in groundwater levels for various regions of the world calculated from the GRACE satellite (Lo et al., 2016; Famiglietti, 2014). The decline in northwestern India is greater than for any other large region of the world considered.

One may wonder if this decline is just another data point on the heterogenous impacts of climate change, as opposed to groundwater extraction. If northwest India is becoming drier than the reservoir may decline even without a change in water extraction. However, this is not the case: geo-physical modeling of water inputs and outputs implies that the rate of extraction has increased (Lo et al., 2016). In fact, surface water reservoirs have generally increased in their holdings over this time, implying that the net contribution of rainfall has increased and the plotted change in reservoir level understates the gross contribution of increasing groundwater extraction to falling groundwater levels (Rodell, Velicogna and Famiglietti, 2009).

(c) Fiscal pressure on state-owned utilities

The direct cost of subsidies is the expenditures of state governments to pay utilities to supply unprofitable customers. Utilities bill governments based on their estimates of consumption in the agriculture sector, and these bills have been rising over time.

In Rajasthan, Figure 2 shows the rapid growth in agricultural subsidy outlays from 2012 to 2016. From USD 160 million per year the subsidies for agricultural power consumption have grown to over USD 1 billion per year. The USD 1 billion number, a little over 3% of the state budget, is almost surely an understatement on the extent of fiscal losses due to agricultural subsidies. These payments represent the explicit cost of agricultural subsidies,

[1] Groundwater depletion has been shown to increase poverty and spark conflict (Sekhri, 2014).

but the government does not reliably pay subsidies to the utilities, and a large part of their cost is accrued as debt on the books of the state-owned power companies. In fiscal 2015-16, the state of Rajasthan assumed utility debt equal to Rs 42,964 crore (USD 7 billion) and in fiscal 2016-17 Rs 20,133 crore (USD 3.4 billion). These amounts were higher than usual, due to a debt-restructuring and reflect accrued losses over perhaps a decade, but give a better sense of scale of the fiscal problem.

(d) Data

We use original agricultural household survey data on farmers in Rajasthan. The survey sampling was done to encompass both current agricultural electricity consumers, with their own grid connections, as well as some farmers without such connections. The data can thus be used to measure the incidence of subsidies across both users or power and some types of potential users.

The study area consisted of six subdivisions, a unit of utility organization, in four districts of Rajasthan. These subdivisions were selected for having a range of groundwater conditions, high numbers of agricultural users of electricity and decent (greater than 65%) rates of metering for agricultural electricity connections. A total of 300 electricity feeders were randomly sampled as primary sampling units from within these subdivisions. A feeder is the 11 kV level of the electricity distribution network and typically serves from fifty to several hundred agricultural consumers.

The sampling of farmers within feeders was done in two stages. The first stage randomly sampled 14 farmers from the formal list of utility customers in that feeder (yielding 4,262 primary respondents in total). The second stage then sampled more farmers based on their input relationships with primary respondents. Farmers who do not have a connection in their own name may (a) share a connection with another relative (b) lease a connection during the growing season (c) buy water from a connection. We sampled these relationships at rates of 35%, 100% and 100% respectively (yielding 2,401 additional "snowball" respondents, who may lack grid connections).

The survey instrument was based on the World Bank's Living Standards Measurement Survey – Integrated Surveys on Agriculture (LSMS-ISA), heavily modified to include more detail on irrigation practices, electricity supply and certain input expenditures. The survey instrument identified all farmers with whom the respondent had an agricultural relationship, in terms of sharing an electricity connection, leasing land in or out, leasing a connection in or out or buying or selling water. Therefore, even for cases where "snowball" respondents were not sampled, we have survey data on one side of the relationship from the first stage respondent.

Interviews were conducted from April to August 2017 with reference to the Rabi 2016-2017 growing season. The Rabi season, which lasts from approximately November through March or April, is the dry season of agriculture in Rajasthan. There is typically minimal rainfall and all cropping is irrigated during this season.

3 Electricity rationing binds

This section presents evidence on how subsidies distort the supply of power. The main finding is that electricity rationing binds, both on the intensive margin of hours of supply and on the extensive margin of how many farmers are allowed to connected to the grid.

(a) Electricity subsidies are large

The electricity subsidy paid on farmers' behalf is large. The mean value of subsidies for farmers' power consumption in the dry season was USD 85. Figure 3 shows the distribution of the subsidy amounts implied by each farmer's seasonal power consumption; the distribution is right-skewed, wtih most farmers receiving less than USD 100 but 15% more than USD 150 and 8% more than USD 200. The value of electricity used in production, gross of subsidy, is roughly as large as the value of chemical fertilizer (not shown).

As a basis for comparison, the average farmer profits in our sample during the rabi season are USD 265. The average subsidy is therefore about one-third of total profits for each farmer. If we assume that farmers use twice as much electricity over the full year as in the dry season alone, then the total annual power subsidy per capita is on average 14% of state per capita GDP (State per capital GDP of INR 72,156 for 2014-15, Niti Aayog).

(b) Intensive margin rationing

Electricity subsidies increase the cost of supplying power to farmers. Rajasthan, like many other Indian states, therefore limits the quantity of supply through rationing. This rationing is visible on both the intensive and the extensive margins.

On the intensive margin, the utility limits the supply of three-phase power, required to run agricultural pumps and other motors, to six hours per day in rural areas.[2] The rationing rule is largely uniform across rural areas, though the block of six hours in which power is supplied rotates over time in each area to smooth out total load. This rationing system is referred to as 'virtual' feeder segregation, because the supply of power for agricultural uses is limited by the period of three-phase supply, even though farmers are not physically connected to different feeders than other electricity consumers. Some Indian states have undertaken physical segregation—building different electricity distribution grids for different customers—to achieve the same end, of rationing farmers, while allowing households

[2]Three-phase alternating current is supplied in three wires, with the timing of the alternating current in each wire offset by one-third of the period between peak voltages. Motors and anything that uses a motor, such as a refrigerator compressor, require three-phase power to operate. Hence domestic electricity customers in the same rural areas are not able to use appliances with motors during the rationed period. They may still use appliances that present resistive loads, like light bulbs.

to have three-phase supply.

Figure 4, Panel A shows that this rule is closely followed in our data; more than 80% of farmers report supply of 6 hours of electricity per day, with the remainder mostly reporting four or five hours. The limited supply of power is binding on power use. Figure 4, Panel B reports farmers' use of power. The modal usage is 5 hours per day, with the distribution bunched up between four and six hours, against the limit imposed by supply rationing. We consider this to be evidence that rationing binds; the small gap between hours of supply and use may be accounted for by farmers needing to turn their pumps on when power starts flowing (some farmers do use auto-starters, which switch pumps on automatically, to use every available minute of supply).

(c) Extensive margin rationing

Because supplying at subsidized rates is costly, the government limits the number of new consumers who can be connected in a year. Each year, this number is set as part of budget negotiations, and implemented by the utility by granting new connections to farmers who have already applied and been waitlisted. The utility grants connections on a first-come first-serve basis based on the date of application.

Figure 4, Panel B illustrates rationing on the extensive margin. The histogram shows the year of connection application for a sample of farmers with pending applications from this register, surveyed in 2016. The distribution shows that most pending consumers applied for their connections in 2009 or after, with a sharp drop in pending applications at earlier dates, due to the applications from those dates having been granted already. Thus the typical waiting period for a new connection is about seven years. This delay, an ordeal mechanism, serves as an additional form of rationing to constrain agricultural power consumption on the grid.

The utility slowed down the issuance of new connections in the last couple years. At the time of writing in February, 2018, the current cut-off date for the granting of connections is February 28th, 2010, meaning that farmers who applied on or before that date are eligible to get connected. The waiting list of farmers who have applied after that date exceeds 300,000 farmers in Rajasthan, which is roughly a quarter of the 1.1 million farmers formally connected to the grid.

Extensive margin rationing implies that many farmers cannot get an electricity connection. We expect to see farmers seek alternative, informal sources of water to the extent they are available. Table 1 shows that a dominant source of this substitution to informal sources is sharing an electricity connection with other farmers (typically, but not always, relatives). Of the respondents in our survey connected to the grid, 47% report that they share their pump with others, with 13% of respondents sharing with two other farmers and 17% with three or more other farmers. In these sharing arrangements, farmers divide the electricity bill and contract over the bill share and amount of pump usage in a season. Farmers on the grid also lease out their connection entirely to others (in 4% of cases) or sell some water from the connection (in another 4% of cases). While the intensity of sharing connections is high, it appears that these informal arrangements may be a poor substitute for grid connections.

The rationing of farmers off of the grid will affect their cropping decisions and productivity to the extent that these informal arrangements are imperfect substitutes for having one's own pump. The scope for physically sharing pumps or selling water is limited to immediate agricultural neighbors. While grid-connection status is not exogenous, we are interested as a first look to compare the characteristics and agricultural production of farmers who are connected to the grid versus those who have applied for, but not yet received, an agricultural connection.

To study the effects of extensive margin rationing, we conducted a smaller agricultural survey that sampled both grid-connected and non-connected farmers. The grid-connected farmers were sampled from the agricultural electricity consumers of the distribution company. The non-connected farmers were sampled off of the waiting list for grid connections in the same areas. Thus the non-connected farmers likely wish to have grid connections at the subsidized rate.

Table 2 compares farmers who have their own grid-connected pump to those who do not. The columns show variable means and standard deviations for farmers who have their own pump (column 1), defined as a pump on their farm, and do not have their own pump (column 2). Column 3 gives the difference in means between these farmer types. Of those farmers who do not have their own pump, 90% (column 1) report having applied for a grid connection. This high number is a result of the sampling frame, which was taken off of the administrative waiting list for connections. Of those who do have a pump on their farm, 17% have applied for a connection. These farmers may presently share a pump with others and wish to have their own, have a connection in their father's name and wish to get it transferred to their own name, or wish to increase their pump capacity.

There are large differences in land-holdings and agricultural revenue between farmers with and without pumps. Farmers with pumps own 1.07 hectares more land than farmers without, and they lease in additional land, so that they control 1.66 hectares more land. Nearly all of the land controlled by both types of farmers is cultivable. Farmers with pumps irrigate 1.71 hectares more land than farmers without pumps. Again, this is greater than the raw difference in land ownership. It appears that farmers with pumps lease in land from others and irrigate it, whereas farmers without pumps cultivate and irrigate only their own land. Farmers without pumps report agricultural revenue of INR 84 thousand (USD 1,400), whereas farmers with pumps report revenue INR 222 thousand higher (USD

3,700). The difference in revenues, a factor of 3.6, is much greater than the difference in land controlled (a factor of 1.7) or irrigated (a factor of 1.8).

These comparisons are not the causal effects of pump ownership. There are likely unobserved variables correlated with both pump ownership and land holdings and agricultural productivity, for example, farmers with pumps that inherited their electricity connections from their families, along with landholdings, and may have inherited other forms of wealth also. Inherited pumps in the name of a farmer's father are very common.

Despite this caveat, there are several results in Table 2 that suggest a causal effect of pump access. First, even conditional on land owned, pump owners control and irrigate more land than non-owners. Thus the difference between owners and non-owners cannot be due only to inheritance or the permanent income effects of greater land ownership. Second, our sampling strategy reduces possible concern about the endogeneity of pump ownership. A comparison of pump owners to all non-owners would typically be biased by the fact that pump owners may be unobservably better farmers, who found it worthwhile to seek a grid connection and expand their farm. In our sample, nearly all of the non-owners are farmers who wish they had pumps, as evidenced by their applications for grid connections. Thus the table conditions on desired pump ownership via the sample selection rule.

The evidence from both the intensive and extensive margins shows that the utility rations power. In effect, the subsidy regime not only depresses price but also fixes quantity, both in terms of hours and farmers connected. The farmers rationed off of the grid, but who wish to be connected, have lesser landholdings and farm less intensively than farmers on the grid.

4 Rationing as second best under water scarcity

This section investigates the effects of water scarcity on farmer adaptation and profits, as a proxy for measuring the effect of power rationing.

The effects of rationing on social surplus and welfare are ambiguous. Given the heavily subsidized price of power, rationing may be preferable to no rationing because rationing can create a shadow price of power. For binding rationing, as we have shown, this shadow price is positive and acts as an incentive for conservation. The shadow price of rationing may be above or below the social cost of water extraction.

The costs of rationing are due to the misallocation of power across farmers. All farmers on the grid are limited to the same amount of power consumed. Unproductive farmers will use more power under the rationing regime, due to subsidies, than they would have if power were priced at social cost. Some productive farmers may wish to use more than the ration, even if power were priced at social cost. Their consumption will be inefficiently low. The consumption of farmers who are rationed off the grid altogether, on the extensive margin, may also be too low; this depends on whether they would be willing to connect and pay for a connection even if power were priced at social cost. In other words, whether the farmers would have queued up even at a higher price.

We study water scarcity as a proxy for rationing, because scarcity and rationing are perfect substitutes, but the rationing regime is uniform across farmers, while scarcity is not. The market for groundwater, which is not priced, clears on the overall cost of extraction, which includes shadow costs for both power rationing and water scarcity. The flow of water that can be extracted from a well is $w \propto P/D$ for power input P and depth D, implying that the quantity of water extracted $W \propto (PH)/D$ for supply hours H and a fixed farmer pump capacity (The Royal Academic of Engineering, 2017). Hence increases in hours of supply increase the total amount of water a farmer can extract and are identical in their effect to a proportional increase in inverse depth (proportional decrease in depth).

(a) Water scarcity raises shadow cost of water

The shadow price of water imposed by water scarcity affects both investment in extraction and farmer cropping and irrigation decisions. Farmers with a higher shadow price of water may plant crops that are more tolerant of low water levels and adopt irrigation measures that conserve the water that can be extracted.

Figure 5 shows evidence of water conservation on these margins for farmers facing a greater groundwater depth. Groundwater depth is measured as the average well depth in the same feeder as the sampled farmer, and runs along the horizontal axis of the plot in each panel. In Panel A, we plot the share of area planted under water-hardy crops (which require less than 400 mm of water) against depth, and in Panel B, the share of area under sprinkler irrigation. Each panel includes a local polynomial regression curve of best fit.

In Panel A, we see that the share of water hardy crops (primarily mustard seed and lentils) in area planted increases from approximately 20% at the shallowest water tables to about 60% at the deepest. Farmers can also change irrigation systems to conserve water. Flood irrigation fills the furrows between rows of plantings with water; sprinkler irrigation broadcasts water across crops and delivers more water to crops relative to losses due to evaporation and re-absorbtion. In Panel B, we show the share of farmers using sprinkler irrigation. At depths below two hundred feet, virtually no farmers use sprinkler irrigation. The share using sprinkers increases from roughly zero at the shallowest groundwater depths to 60% at the deepest.

Given a fixed supply of power, farmers could increase their water supply mainly by investing in more powerful extraction technology. The capacity of a farmer's pump, in horsepower, determines how much input energy the farmer can use during a fixed supply window. The size of pumps is largely fixed at the time of the farmer being granted a grid connection, though farmers may rewind or attempt to increase their pump sizes. The depth of a farmer's well is therefore one of the only margins to increase how much water he can draw.

Figure 6 suggests how groundwater depletion has changed investment on the margin of well depth over time. The figure plots the depth of a well against the year a well was drilled. As groundwater levels decline, deeper wells are required to reach water. On average, the depth of drilled wells is increasing six feet per year from 2007 through 2017. Prior to the year 2000, very few very deep wells, of over 500 feet, were drilled at all, whereas of wells drilled from 2010 onwards one quarter are of depth 500 feet or more. Chasing water as it retreats into the ground is costly. Farmers bore a new well on average every eight years at an expenditure of INR 68 thousand (USD 1,133) per well, a cost which rises to INR 95 thousand (USD 1,583) for wells greater than 500 feet.

The evidence shows a power supply regime wherein large power subsidies do not alleviate water scarcity nor does power rationing restore a sustainable rate of groundwater extraction. Even under rationing, water extraction exceeds the regeneration of the groundwater reservoir, and so water tables decline. This decline requires compensatory investments in irrigation and well boring to sustain agriculture.

(b) Water scarcity and profits

This subsection studies the effect of water scarcity on farmer yields and variable profits. Despite compensatory investments and adaptation, farmer profits may decline with water tables. Under power rationing, the amount of power input available to farmers is fixed and therefore cuts off one margin of adaptation; farmers must use less water (for a given pump size) as depth increases.

We study the effects of water scarcity using cross-sectional, hedonic regressions of farmer profits on depth to groundwater. There is a huge range of cross-sectional variation in groundwater depth in Rajasthan and, by design, within our sample (see Figure 5). The advantages and disadvantages of the Ricardian, cross-sectional approach are well-studied in the climate literature. The advantage of using a cross-sectional approach is that it accounts for adaptation and recovers a longer-term effect of water scarcity than using short-term shocks (Mendelsohn, Nordhaus and Shaw, 1994; Mendelsohn, Dinar and Williams, 2006; Schlenker, Hanemann and Fisher, 2005). A potential disadvantage is the presence of unobserved variables correlated with both depth and farmer productivity.

The regression specification is

$$y_{sfic} = \beta_0 + WellDepth_{sf}\beta_1 + X'_{sfic}\beta_1 + \alpha_s + \varepsilon_{sfic}$$

where $WellDepth_{sf}$ is the average depth of farmer wells in feeder f served by utility sub-divisional-office (SDO) s, X_{sfic} are exogenous controls for farmer i growing crop c in feeder f and SDO s, α_s are SDO fixed-effects and ε_{sfic} is an error term. We allow ε_{sfic} to be arbitrarily correlated within feeder since average well depth varies only at the feeder level (across 300 feeders). We specify a parsimonious set of exogenous controls X_{sfi} including land size effects and the share of a farmer's land that is formally registered.

We use three outcome variables: yields (quintals per hectare), cash profits and cash profits plus own consumption. The survey directly asked farmers for crop-level profits; farmers typically understand this to be on a cash basis and exclude the value of agricultural products retained for own consumption. We therefore calculate an imputed profit measure that adds back in the value of own consumption and storage.[3] We do not deduct from

[3]We impute prices for own-consumed products using the median crop price on sales within an SDO and crop.

profits any adjustments on the cost side, such as the value of own labor, so the level of this variable should be considered an upper bound

Table 3 reports estimates of the above regression where the coefficient of interest is on well depth. Column 1 has no controls, column 2 adds the share of land that is formal, column 3 adds fixed effects for deciles of plot size and column 4 adds fixed effects for SDO (the sample was drawn from six SDOs). In Panel A we report results for yield. There is a negative and statistically significant effect of well depth on yield in columns 1 through 3, without SDO fixed effects. The magnitude is fairly small, such that a one standard deviation (140 foot) increase in well depth decreases yield by 3 quintals per Ha, or about 7% of the mean yield. The yield effect is even smaller and not statistically significant when estimated within SDO (column 4).

The small effects of water scarcity on yields may be due to adaptation to water-hardy crops and irrigation techniques as observed above. Farmers may grow drought-tolerant but less valuable crops to offset water scarcity. To test this idea, we look at variable profits, as defined above, as our outcome variable.

Table 3, Panel B reports estimates for cash profits. Profits are steeply decreasing in well depth. With plot decile effects but without SDO controls (column 3), the point estimate is INR -36.9 per hectare per foot of depth (standard deviation 7.87), such that a one standard deviation increase in well depth reduces profits by INR 5,166 (USD 86), or as much as removing the electricity subsidy altogether without changing power consumption (recall, the mean subsidy value was USD 85). The coefficient estimated within-SDO (column 4) is larger, at INR -47.7 per hectare per foot of depth.

In Panel C, we add back in the imputed value of own consumption and storage at market prices. This adjustment is important as the quantity of crops retained for own use is roughly the same as the quantity sold in our sample. Using all variation in well depth (columns 1 through 3), well depth has smaller and insignificant effects on this measure of total profits. In column 4, we add back SDO fixed effects. The coefficient estimated within-SDO is again negative and larger, at INR -30.4 per hectare per foot of depth.

Overall water scarcity is estimated to reduce farm profitability. Farmers in water-scarce areas have much lower cash profits (Panel B). We can infer from the difference in Panels A and B, columns 1 through 3, that the value of own consumption is increasing in well depth, to offset the effects seen in Panel B, columns 1 through 3. Thus households in water-scarce areas sell less on the market relative to own consumption. Looking within areas, well depth decreases profits including the value of own consumption.

(c) Efficiency of rationing

The rationing policy is uniform for all farmers in the state. The equivalence between hours of supply and inverse depth allows us to use the relationship between profit and water scarcity to estimate the social surplus from relaxing the power rationing regime.

Consider a relaxation of rationing from six hours per day to seven. We assume that for this marginal relaxation, rationing will continue to bind and all farmers will now use seven hours. An increase in hours of supply by 1/6 has the same effect on farmer water availability as a reduction in depth by 1/6; applying this to the mean depth,

$$\Delta D = (1 - 7/6)\overline{D} = (1 - 7/6) \times 285 \text{ ft} = -47.7 \text{ ft}$$

Multiplying our Table 3, Panel C, column 4 linear estimate $\hat{\beta}_1 = -30.4$ by this change in depth implies a change in profits of INR 1449 per Ha (USD 24) per crop-season. This increase in profits represents the change in farmer profits from a relaxation of rationing and therefore the marginal social benefit from this relaxation.

The cost side of the increase in power supply is the cost that the government has to pay for the additional power. We assume that the nominal price of electricity to the farmer of INR 0.90 per kWh is paid in full *and* accounted for in farmer estimates of profits. Therefore the additional cost to the government, not covered by additional transfers from farmers, is only the subsidy of INR 3.85 per kWh. At this rate, the average farmer-crop will use an additional value of subsidy in the season of

$$\begin{aligned} MarginalSubsidy_{ic} &= \frac{PumpCapacity \text{ HP}}{LandArea \text{ Ha}} \times \frac{1 \text{ kW}}{1.34 \text{ HP}} \times \frac{1 \text{ hour}}{1 \text{ day}} \times \\ &\quad \frac{IrrigationDays \text{ days}}{1 \text{ season}} \times \frac{\text{INR } 3.85}{1 \text{ kWh}} \\ &= \frac{7.26 \text{ HP}}{0.70 \text{ Ha}} \times \frac{1 \text{ kW}}{1.34 \text{ HP}} \times \frac{1 \text{ hour}}{1 \text{ day}} \times \frac{41.74 \text{ days}}{1 \text{ season}} \times \frac{\text{INR } 3.85}{1 \text{ kWh}} \\ &= \text{INR } 1243.79 \text{ per Ha-season.} \end{aligned}$$

In the second line we have substituted the average values of all parameters from our survey data, namely and respectively: the average pump capacity used by grid-connected farmers, the average land area planted per crop, and the average number of irrigation days per crop in a season. The calculated marginal subsidy of INR 1244 per Ha (USD 21 per Ha) is close to the marginal benefit of INR 1449 per Ha (USD 24 per Ha) calculated from the increase in farmer profits; we could not reject that they are the same, given the uncertainty in $\hat{\beta}_1$. This would suggest that the degree of rationing is nearly optimal in maximizing social surplus.

However, the calculation above has assumed that the social cost of water is *only* the cost of the power used to pump it out of the ground. The true social cost of water in a renewable reservoir is the opportunity cost of using that water in the future (Timmins, 2002). A full surplus analysis would account for this dynamic cost and thus estimate a higher social marginal cost from relaxing rationing than we have estimated here. Hence we tentatively conclude that the efficient (surplus maximizing) rationing regime would supply less than six hours per day. One interpretation is that the government and utility have set a rationing regime that internalizes their private costs of power supply, but not the opportunity cost of water extraction.

5 Conclusion

When prices are extremely distorted a market is likely to clear on some other margin. We have shown, in the case of power rationing of Indian farmers, that the market for power clears on government rationing, and that the market for water therefore clears on water scarcity.

The paper uses the equivalence between power rationing and inverse water depth to estimate the efficiency of the rationing regime, in several steps. First, we show that rationing indeed binds. Second, we estimate the effect of water scarcity on agricultural profits in a Ricardian approach, after the climate literature. As an ancillary result we show that farmer adaptation to water scarcity, such as through water-conserving investment, crop choice and well-drilling, is able to sustain yields, but not profits, in water-scarce conditions. Third, we translate the effect of water scarcity into an equivalent relaxation of the rationing regime. We find that the marginal benefits (increased farmer profits) and private marginal costs (increased electricity production cost) from a relaxation of rationing are roughly equal. However, since the private marginal costs omit the opportunity cost of water, they are below social costs. The current rationing regime, by implication, is probably too generous, despite its severity.

The analysis of marginal surplus here may be extended in time or in breadth. In time, a full accounting of the cost of water would require specifying and solving a dynamic problem of optimal reservoir depletion, where the utility may be constrained to use a limited set of instruments for princing and allocating power. In breadth, we have taken the joint rationing and supply regime here as given. However, in the presence of liquidity constraints a rationing or quota regime may actually be second-best, and achieve greater efficiency than a price-based regime (Donna and Espín-Sánchez, 2016). Market failures limiting the use of intermediate inputs, like water and fertilizer, are commonly cited as reasons for low productivity in developing-country agriculture (Donovan, 2017). There is sharp evidence for such failures in insurance, for example (Karlan et al., 2014). Similar market failures may justify the utility providing power free of cost to increase the productivity of cash-poor but productive farmers.

On the reform of the subsidy-and-rationing regime, the above discussion of second-best efficiency presupposes that the government is not able to make lump-sum transfers to farmers. The technology for making such transfers has improved over time (Muralidharan, Niehaus and Sukhtankar, 2016). With growth in state capacity, it may be that farmers can be granted an electricity subsidy in a lump-sum form to offset cash constraints while retaining the efficiency of marginal pricing. Under such a regime, all farmers could afford power as an intermediate input, but rationing would not be needed to constrain the consumption of farmers who are not credit constrained. We are exploring this idea in a field experiment run jointly with the electric utility in Rajasthan.

The importance of the question of how to best manage groundwater resources is growing, along with the depth to groundwater tables, year after year. The only price for groundwater in India is the price of power; otherwise, the resource is entirely in common and unmanaged. India uses more groundwater than the United States and China combined, with nearly all of it being used for irrigation National Ground Water Association (2016). The future availability of this resource will help farmers to adapt to climate change (Schlenker, Hanemann and Fisher, 2005). While there have been great improvements in agricultural technology, including towards drought resistant and water hardy crops, the scope for adaptation is limited. Moreover, the markets that would allow smallholders to protect themselves from water depletion, such as markets in insurance and land, are thin to non-existent in many developing countries. Reform in the power sector, on rationing and subsidies, would therefore serve only as one part of a broader water and climate policy to protect farmers against profound shocks.

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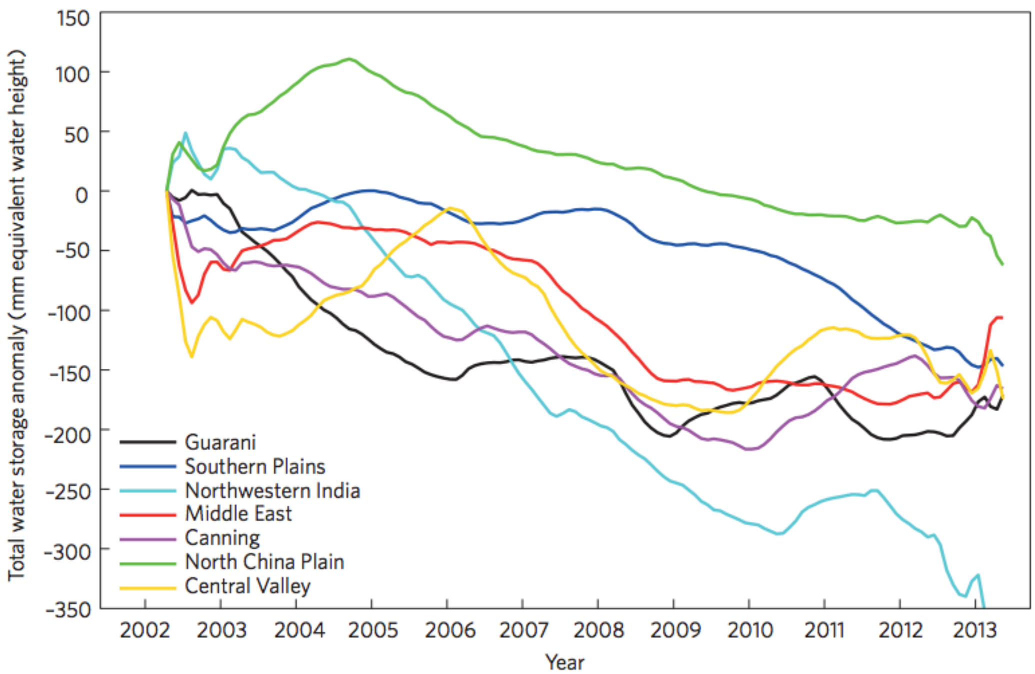
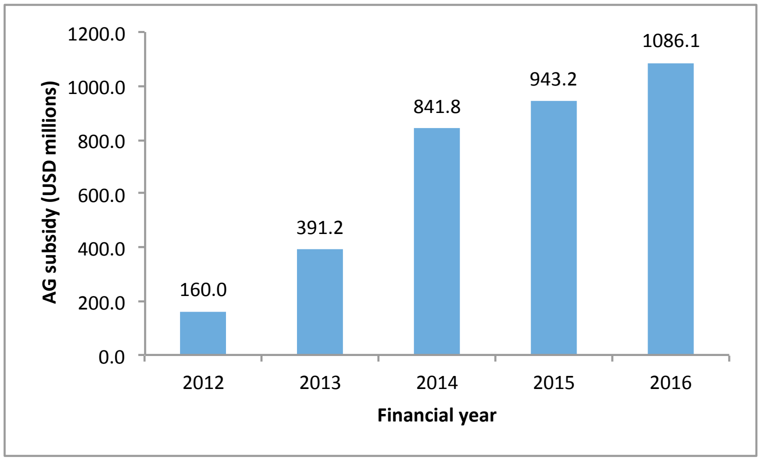
6 Figures

Figure 1: Groundwater Depletion in Northwest India, 2002 to 2013



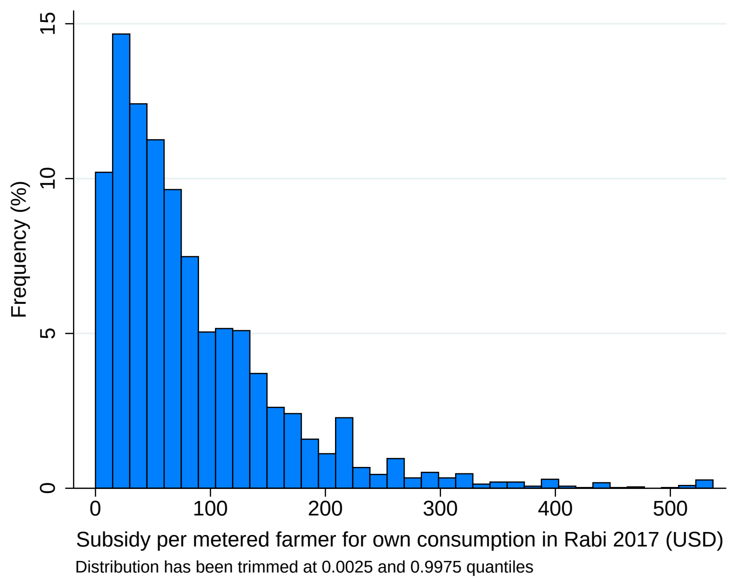
The figure is reproduced from Famiglietti (2014), Figure 2 and shows the declines in water storage in various large aquifers around the world. The units are millimeters of equivalent water height. Data is from the NASA GRACE satellite mission.

Figure 2: Growth of Explicit Agricultural Electricity Subsidies



The figure shows subsidy payments from the Government of Rajasthan to the publicly-owned Rajasthan electricity distribution utilities for subsidies to agricultural electricity consumers.

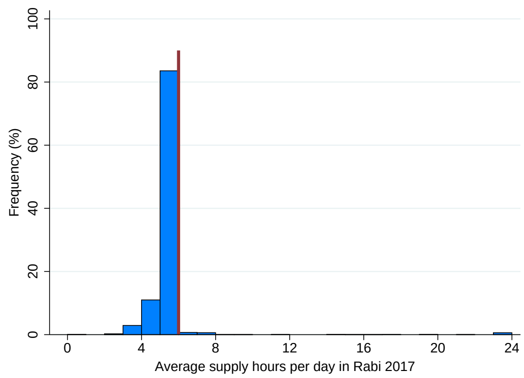
Figure 3: Distribution of electricity subsidies across farmers



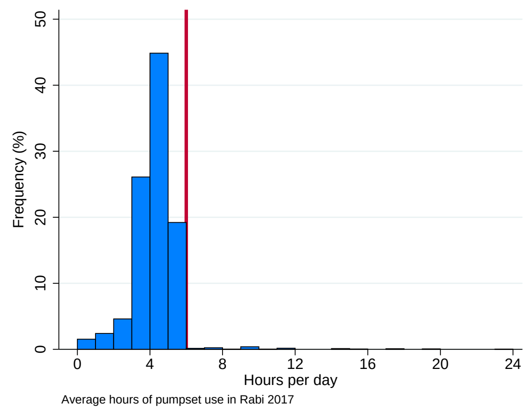
The figure shows agricultural electricity subsidies calculated on the basis of farmers' imputed energy consumption during the rabi season of 2016-17. Energy consumption is imputed based on hours of use and pump capacity.

Figure 4: Rationing of Power Supply

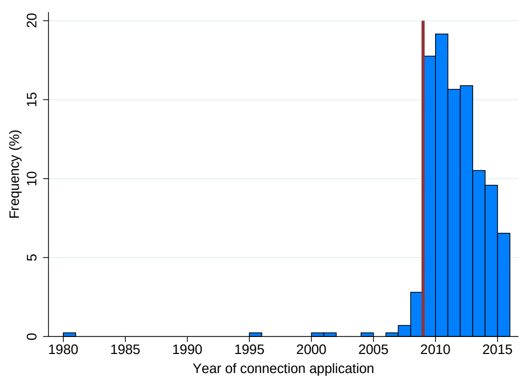
Panel A. Intensive Margin: Hours of Supply



Panel B. Intensive Margin: Hours of Use



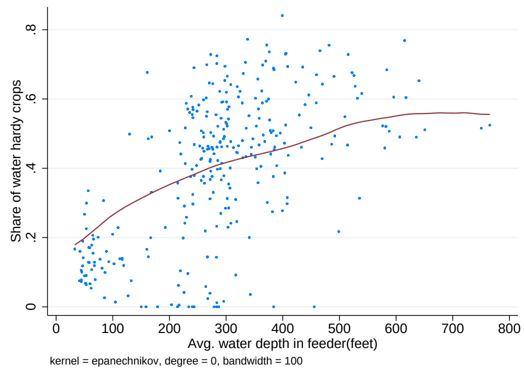
Panel C. Extensive Margin: Delay in Connections



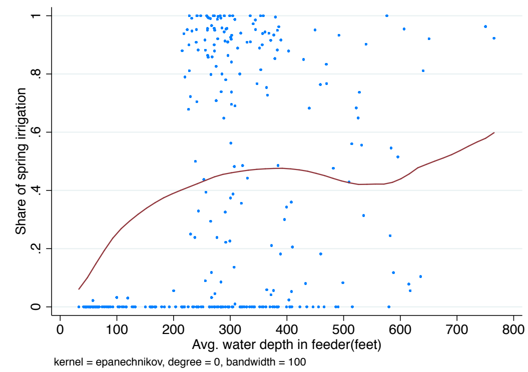
The figure shows evidence of power rationing using data from household surveys of farmers with existing agricultural electricity connections (Panels A and B) and farmers with applications for agricultural electricity connections (Panel C). Panel A shows the distribution of the average hours of supply per day during the Rabi season of 2016-2017. Panel B shows the distribution of the average hours of use. Panel C shows the year of application for an agricultural electricity connection, amongst a sample of farmers with pending applications interviewed in 2016.

Figure 5: Water Scarcity and Cropping Choices

Panel A. Water Hardy Crop Share by Well Depth

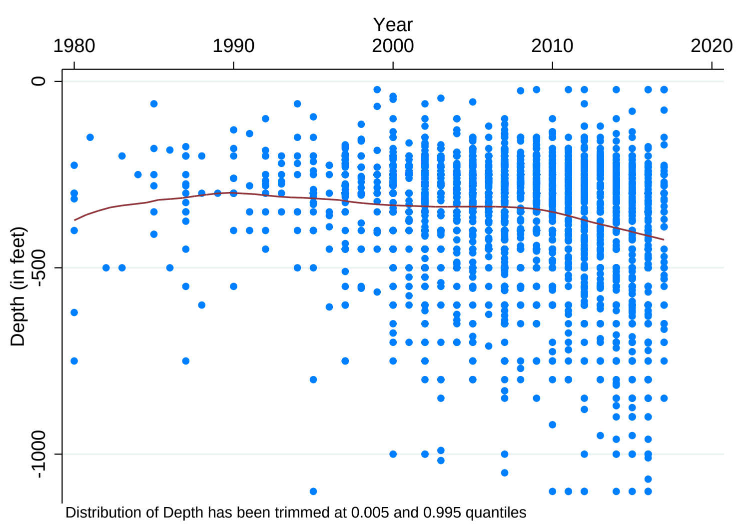


Panel B. Water Conservation by Well Depth



The figure shows the relation between farmer crop choice (Panel A) and water conserving technology (Panel B) and well depth. The crop choice margin is the share of crop area planted under crops with an agronomic water requirement of less then 400 mm (Panel A). The water conserving technology is the share of area under sprinkler irrigation (Panel B). In each panel a dot represents one survey respondent and the curve is a local polynomial line of best fit.

Figure 6: Depth of farmer wells by year drilled



The figure shows the depth of an irrigation well against the year in which the well was drilled, based on recall in the farmer survey. Each point represents a well and the curve is a local polynomial fit.

7 Tables

Table 1
Informal Substitutes for Grid Connection

	Number	%
Grid-connected farmers	4264	100.00
Any type of joint usage	2260	53.03
Share pump (=1)	2012	47.21
with one other	712	16.71
with two others	560	13.14
with three others	370	8.68
with >= 4 others	370	8.68
Lease Connection	169	3.97
Sell Water	160	3.75

The table shows the ways that farmers connected to the grid share their pumps or sell their pumps' output. The top line is the number of grid-connected survey respondents, sampled from those with electricity connections. The rows below show the number and percentage of these grid-connected respondents that share their pumps with others, lease their connection out at least part time, or sell water to others.

Table 2
Farmer Characteristics by Pump Ownership

	Farmer has own pump		
	No	Yes	Yes − No
	(1)	(2)	(3)
Applied for connection (=1)	0.90	0.17	-0.72***
	[0.31]	[0.38]	(0.022)
Land owned (Ha)	2.22	3.29	1.07***
	[2.93]	[4.49]	(0.22)
Land controlled (net of leasing) (Ha)	2.40	4.06	1.66***
	[2.99]	[5.56]	(0.24)
Land cultivable (Ha)	2.25	3.92	1.67***
	[2.92]	[5.33]	(0.23)
Land irrigated (Ha)	2.18	3.89	1.71***
	[2.82]	[5.31]	(0.23)
Revenue, agriculture (INR '000s)	83.8	305.6	221.7***
	[233.8]	[1262.7]	(36.4)
Observations	250	1441	1691

The table shows the characteristics of farmers based on whether they own a pump. The data is from a pilot survey that sampled both grid-connected farmers and farmers who had applied for, but not yet received, a connection to the grid. The sampling frame for the latter group was the waiting list of not-yet-connected farmers. Each cell within columns (1) and (2) shows the mean [standard deviation] of the row variable. Column (3) shows the difference in means and the standard error of the difference in means between farmer groups. All variables have the sample size reported in the final row except for Applied for connection (=1), for which the sample sizes of each column are 250, 1173 and 1423, respectively. In column (3) * indicates $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3
Profits and Water Scarcity

	(1)	(2)	(3)	(4)
Panel A. Yield (quintals per Ha)				
Mean well depth (feet)	-0.023^{**}	-0.024^{**}	-0.021^{**}	-0.011
	(0.0095)	(0.0096)	(0.0094)	(0.011)
Formal land (percent)		0.23^{***}	0.18^{***}	0.29^{***}
		(0.038)	(0.034)	(0.073)
Plot decile effects	*No*	*No*	*Yes*	*Yes*
SDO fixed effects	*No*	*No*	*No*	*Yes*
Mean dependent var.	40.73	40.73	40.73	40.73
Observations	11883	11785	11785	11698
Panel B. Profit, reported (cash) (INR per Ha)				
Mean well depth (feet)	-30.2^{***}	-30.2^{***}	-36.9^{***}	-47.7^{***}
	(7.75)	(7.68)	(7.87)	(9.77)
Formal land (percent)		139.6^{***}	169.9^{***}	-24.8
		(34.4)	(31.8)	(30.7)
Plot decile effects	*No*	*No*	*Yes*	*Yes*
SDO fixed effects	*No*	*No*	*No*	*Yes*
Mean dependent var.	-12224.34	-12224.34	-12224.34	-12224.34
Observations	4091	4058	4058	4052
Panel C. Profit, reported plus own consumption (INR per Ha)				
Mean well depth (feet)	7.83	5.10	6.90	-30.4^{***}
	(7.05)	(7.05)	(6.68)	(6.17)
Formal land (percent)		349.6^{***}	294.8^{***}	78.4^{**}
		(38.6)	(37.8)	(37.8)
Plot decile effects	*No*	*No*	*Yes*	*Yes*
SDO fixed effects	*No*	*No*	*No*	*Yes*
Mean dependent var.	30455.30	30455.30	30455.30	30455.30
Observations	11883	11785	11785	11698

The table reports coefficients from hedonic regressions of agricultural profit on mean well depth in a farmer's area and control variables. The data is from the main agricultural household survey and the observations are at the farmer-by-crop level. The dependent variable changes in each panel. In Panel A, the dependent variable is yield (quintals per Ha), in Panel B, it is farmer reported profits (INR per Ha), where reported profits are assumed to be on a cash basis and do not value own consumption, and in Panel C, it is farmer total profits (INR per Ha), where total profits are calculated as reported profits plus the value of own consumption and storage. Mean well depth is the average well depth from all farmers in the same feeder as a given farmer, where the feeder is the lowest level of the electricity grid (serving 50-200 farmers). SDO fixed effects are dummy variables for each of the six sub-divisional offices of the distribution company from which farmers were sampled. Standard errors are clustered at the feeder level, at which mean well depth varies. The statistical significance of a coefficient at certain thresholds is indicated by $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.