Electricity Prices, Groundwater and Agriculture: The Environmental and Agricultural Impacts of Electricity Subsidies in India*

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Abstract

In this paper we estimate the effect of agricultural electricity subsidies in India on groundwater extraction and agricultural output. Our empirical approach exploits changes in state electricity prices over time controlling for aggregate annual shocks and fixed district unobservables. Electricity subsidies meaningfully increase groundwater extraction, where the implied extensive margin price elasticity is -0.18. This subsidy-induced change in groundwater extraction impacted agricultural output and crop composition, increasing the value of water-intensive output and the area on which these crops are grown. These subsidies also increase the probability of groundwater exploitation, suggesting that they may come at an unintended and long-term environmental cost.

JEL: H20, O13, Q4, Q25

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1 Introduction

In developing countries energy subsidies are significant, totaling over \$220 billion (in 2005) for the largest twenty non-OECD countries (UNEP 2008). Nearly half of these subsidies are directed at rural households, primarily as electricity subsidies. The rationale is that agricultural electricity subsidies stimulate agricultural production through enhanced groundwater irrigation, benefiting poor rural households and stabilizing food prices. Yet little is known about the causal impact of agricultural electricity subsidies on groundwater usage and agricultural output, despite their ubiquity as an agricultural policy tool and the magnitude of resources devoted to them (Birner et al. 2007, Fan et al. 2008, Gandhi and Namboodiri 2009, Kumar 2005, Mukherji and Shah 2005, Scott and Shah 2004).[1,2]

We investigate these questions within the context of India, where approximately \$US 10 billion was spent in 2005 alone on agricultural electricity subsidies. These subsidies comprise the largest expenditure item in many state budgets, leading many to wonder about their impacts on agricultural production and the opportunity cost of not allocating these funds elsewhere (Tongia 2003). Anecdotal evidence has linked India's growth in groundwater irrigation, largely fueled by electricity subsidies, to increased agricultural yields, lower food prices and increased demand for agricultural labor (Briscoe and Malik 2006, Modi 2005, Murgai 2001, Rosegrant et al. 2009). Others suggest that these subsidies have substantial environmental costs, including groundwater over-exploitation (Kumar 2005; Shah et al. 2003, Shah 2009). However, largely driven by data limitations, few studies have isolated the impact of these subsidies on groundwater extraction and over-extraction, or their potential to raise agricultural output (Banerji et al. 2012, Banerji et al. 2013, Ray and Williams 1999,

[1]There is however (in India) a long literature discussing the linkages between electricity subsidies, groundwater extraction and agricultural output (Badiani et al. 2012, Gandhi and Namboodiri 2009, Mukherji and Shah 2005, Scott and Shah 2004). Some of these studies rely on interviews or survey data to show a strong positive correlation between subsidies, extraction and agricultural output (Birner et al. 2007, Fan et al. 2008, Kumar 2005, Scott and Shah 2004).

[2]See Schoengold and Zilberman (2005) for an overview of irrigation, including a discussion on the role of electricity subsidies, in developing countries.

Somanathan and Ravi 2006).[3]

In this paper, we seek to isolate the extent to which agricultural electricity subsidies impacted groundwater extraction and agricultural production between 1995 and 2004. A unique feature of agricultural electricity prices during our period of study is that almost all agricultural users exclusively pay a flat monthly fee for electricity. In other words, they do not face a volumetric charge for electricity. These flat monthly tariffs are primarily determined by State Electricity Boards, entities that are run and controlled by the state government. Guided by these features of our setting, we measure agricultural electricity prices as a fixed monthly rate that is set annually by each state, and exploit variation in electricity prices across states over time. We focus on changes in fixed rates as opposed to changes in volumetric rates since this tariff structure is the status quo agricultural pricing regime, making it the relevant setting in which to evaluate the effect of price changes on groundwater extraction and agricultural production. Given the tariff structure and the nature of our data, we posit that reductions in fixed fees influence groundwater extraction through the adoption and expansion of tubewell irrigation.

Using novel panel data from 344 districts, our empirical approach uses year-to-year variation in state electricity prices to compare a given district's groundwater demand under various prices, controlling for aggregate time shocks. The main identifying assumption behind this strategy is that electricity prices are orthogonal to other time-varying state and district determinants of groundwater demand. However, there are many reasons why electricity prices might be systematically correlated with time varying state unobservables that influence groundwater demand and agricultural production. First, politicians have used elec-

[3] Exceptions include simulation-based and empirical studies that seek to understand the impact of moving from a fixed rate to volumetric pricing structure for agricultural electricity. One study simulates the impact of removing electricity subsidies on groundwater extraction and agricultural yields in North India, and suggests that marginal cost pricing would increase yields and farm profits (Banerji et al. 2012). Another exploits a natural experiment to isolate the effect of a shift from fixed rates to volumetric rates on groundwater extraction and agricultural output (Banerji et al. 2013). A third study estimates the elasticity of demand for agricultural water and then simulates the effect of marginal cost electricity pricing on water demand (Somanathan and Ravi 2006). Finally, recent work evaluates the water and electricity impacts of a pilot program in which farmers voluntarily installed meters and were compensated on a volumetric basis for water savings (Fishman et al. 2014).

tricity pricing as a political tool and state-electoral cycles may be related to other state policies that influence agricultural production and groundwater extraction (Min 2010, Dubash and Rajan 2001). Price may also be systematically correlated with demand for other agricultural inputs such as fertilizer, or supply side electricity constraints in generation and transmission. Motivated by these observations, we gauge the plausibility of our identifying assumption by testing the robustness of our results to the inclusion of time-varying state and district observables.

Our results indicate that an increase in the monthly fixed rate of electricity decreases groundwater extraction along the extensive margin and the probability of groundwater over-exploitation. Our estimates imply a extensive margin price elasticity of -0.18, and fit within the range of elasticities reported in meta-analysis (Scheierling, Loomis and Young 2006). The relatively inelastic response to changes in fixed costs may be explained features unique to the electricity sector in India. First, volumetric prices are zero so changes in electricity tariffs should only affect the decision to adopt and expand tubewell irrigation. Second, though we observe and exploit sizable variation in electricity prices, this observed variation is small relative to the size of the subsidy. The relatively small price signal may dampen the groundwater response to price changes. Third, shortages and rationing of electricity imply that a limited supply may be the binding constraint for electricity, and hence, groundwater demand. Even with these caveats, we find that electricity subsidies meaningfully increase the probability of groundwater extraction and over-exploitation, suggesting that there are likely long-run environmental costs from this policy.

These results add a critical data point to the growing literature on the price elasticity of demand for irrigated water in developing countries and bring an empirical perspective to bear on the theoretical literature surrounding the optimal management of groundwater (Huang et al. 2010, Sun et al. 2006). Obtaining credible elasticity estimates is a critical and necessary step to the design of groundwater management plans, and more generally climate change policies that account for increased variability in precipitation and increased frequency of drought. This is of particular importance in India, where groundwater irrigates 70 percent of irrigated agricultural land. Our results provide insights on the potential for price to encourage groundwater extraction on the extensive margin, and suggest that even under a fixed fee pricing regime agricultural customers are sensitive to prices. We also provide an empirical counterpart to the rich theoretical and simulation-based literature on the economics of groundwater management (Gisser 1983, Ostrom 2011, Ostrom 1990, Provencher and Burt 1993, Strand 2010). Importantly, we test a fundamental assumption underpinning the theoretical literature - namely that groundwater extraction and exploitation respond to price changes.

A second set of results demonstrates that subsidy-induced increases in groundwater extraction increase the value of agricultural output, particularly for water intensive crops. The implied price elasticity of -0.29 for water-intensive agricultural output is consistent with the few existing estimates on the input price elasticity of agricultural output in India, though both our choice of agricultural input and our panel data approach differ from the previous literature (Lahiri and Roy 1985). We also find that for water-intensive crops, farmers are responding along the extensive margin, increasing the area on which crops are grown. The implied elasticity of acreage to groundwater demand is 0.12, and fits within the range of irrigation elasticities (for area) reported by others (Kanwar 2006). These results provide some of the first empirical confirmation that agricultural electricity subsidies achieved the intended objective of increasing agricultural production through the channel of irrigation, and build on an emerging literature that considers the long and short-run agricultural impacts of access to groundwater (Hornbeck and Keskin 2014, Sekhri 2011).

Finally, we explore one efficiency cost of this policy by calculating the efficiency gains from reducing this subsidy by 50 percent.[4] Conditional on certain assumptions, our back of the envelope calculation reveals that the efficiency losses from this subsidy are small, amounting to 9 percent of every rupee spent. While electricity subsidies may create distortions in

[4]The ideal exercise would also simulate the efficiency gains in shifting from flat-rate to volumetric pricing for electricity.

agricultural production and groundwater consumption, a coarse estimate suggests that the deadweight loss from them is low (Gisser 1993, Rosine and Helmberger 1974). These low efficiency costs are likely driven by three unique features of our setting: the absence of volumetric prices, the magnitude of subsidies for electricity, and constraints on the available electricity supply. Incorporating these considerations into demand estimates would likely increase the price elasticity for electricity, and magnify the efficiency costs of these subsidies.

2 Electricity Prices and Tubewell Adoption

With the passage of the Electricity Supply Act of 1948, generation, transmission and distribution of electricity in India was transferred from private ownership to state control. As part of this act, each state formed a vertically integrated State Electricity Board (SEB) responsible for the transmission, distribution and generation of electricity, as well as the setting and collection of tariffs (Tongia 2003). Until the early 1970s, the SEBs charged a volumetric rate for electricity based on metered consumption.

In an effort to increase agricultural production, the government of India in the 1960s began to subsidize a number of key agricultural inputs. This included an agricultural electricity subsidy that was implemented to encourage groundwater irrigation. Evidence suggests that this subsidy indeed increased agricultural energy use which jumped from just 3% of total energy use to 14% by 1978 (Pachauri 1982). During the 1970s and 1980s the number of tubewells also substantially increased. Due to the transaction costs involved with the metering of these newly installed tubewells, the SEBs introduced flat tariffs for agricultural electricity.

As agricultural profits increased and recognition of the importance of agricultural input subsidies grew, farmers began to organize themselves into political coalitions. Around the same time, political competition among state political parties was growing. To attract the agricultural vote, politicians took to using electricity pricing as a campaign tool. We see the first evidence of this in 1977, when one political party in Andhra Pradesh promised free power for agricultural electricity users if elected (Dubash and Rajan 2001). This practice only intensified over time and by the 1980s cheap agricultural electricity was a common campaign strategy, especially in agricultural states (Dubash 2007). Throughout our period of study, electricity pricing remains a powerful political tool. Indian politics is often said to come down to bijli, sadak, pani (electricity, roads, water), an observation that has been corroborated in household data (Min 2010, Besley et al. 2004).

The electricity pricing strategies of SEBs have been linked to a number of negative features of the electricity sector (Cropper et al. 2011, World Bank 2010). First, it has been argued that they are partly responsible for the financial insolvency of the sector. Though SEBs are required to generate a 3 percent annual return on capital, they operate at huge annual losses, totaling US $6 billion or -39.5% of revenues in 2001 (Lamb 2006). Second, the financial instability of the electricity sector combined with low retail prices, likely contributes to the intermittent, unpredictable and low quality electricity service that characterizes electricity provision in India (World Bank 2010, Lamb 2006, Tongia 2003). Third, these subsidies may impose a drag on industrial growth. To partly recover costs, the SEBs charge commercial and industrial users rates that often exceed the marginal cost of supply.

Perhaps, most concerning is the magnitude of these subsidies. The revenue losses from the electricity sector were the single largest drain on state spending and were estimated to amount to roughly 25% of India's fiscal deficit in 2002 (Mullen et al. 2005, Tongia 2003, Monari 2002). As context, the amount spent on agricultural electricity subsidies was more than double expenditure on health or rural development (Mullen et al. 2005, Monari 2002). Expenditures on agricultural electricity subsidies are likely to come at the cost of other social programs. Given the resources dedicated to these subsidies, it is important to quantify if and to what extent they encouraged groundwater extraction.

One unique feature of agricultural electricity prices in our setting is that during our period of study almost all agricultural customers pay only a flat monthly fee, measured in rupees per horsepower, for electricity. That is, the volumetric rate per kilowatt hour (kWh) is zero. This rate structure is motivated in part from the fact that electricity usage for agricultural users is determined largely by pump size. Knowing this, the regulator can set monthly fixed fees that vary across pump capacity to achieve (in theory) a uniform implied price per kWh. In most states, customers face an uniform rate per horsepower (and hence kWh) across pump capacities.[5] For example, assume that one household has a 4 horsepower pump that utilizes 400 kWh in a month while another has a 8 horsepower pump that uses 800 kWh per month. If the fixed fee for the farmer with the larger pump is double that of the farmer with the smaller pump, then the two users would face the same price per horsepower and implicit price per kWh. Regardless of whether a flat implicit volumetric price is achieved, this tariff structure only influences a customer's decisions on whether to install or operate and pump, and what size pump to install. Conditional on these choices, a change in the fixed cost should have no impact on groundwater usage.

Given the ownership structure, financing options, and costs incurred with constructing and maintaining tubewells, it is likely that the decision to install, adopt or maintain a shallow or deep tubewell will be sensitive to electricity prices. Most wells in India are privately owned and financed. Data from the Minor Irrigation Census of India indicate that during our study period approximately 95% of shallow and 62% of deep tubewells were owned by individuals. Over 60% of these wells were self-financed, implying that farmers did not rely on private loans, bank loans or government funding. The upfront costs to construct a deep and shallow tubewell are substantial totaling at approximately \$1500 (or 1 lakh Rs) and \$750, respectively, in the Fourth Wave of the Minor Irrigation Census. Further, roughly 45% of farmers spend between \$15 and \$150 dollars annually to maintain these tubewells. For comparison, the average annual cost to operate a 4 horsepower pump in our sample is roughly \$60 or 8% of the cost of a shallow tubewell.

The strong link between electricity and groundwater use is guided by mechanical features of groundwater irrigation infrastructure and the regulatory landscape governing groundwater

[5]In a few states with tiered rates, the monthly fixed cost per horsepower varies by pump size.

use in India. Most deep and shallow tubewells rely on electricity to pump water to the surface. These farmers face a marginal price for electricity consumption of zero, and landowners face no limitations on groundwater extraction (Gandhi and Namoodiri 2009). This creates a setting where the only constraints on groundwater pumping are pump capacity and the availability of the power supply.

3 Empirical Approach

This section describes the empirical strategy employed to test if groundwater demand is responsive to changes in agricultural electricity tariffs, and then poses an approach to investigate how subsidy-induced changes in groundwater extraction impact agricultural production.

3.1 Demand for Groundwater

To begin our examination of the effect of a change in electricity prices in year t and state j on groundwater extraction in district i, we estimate an OLS model with district and year fixed effects and standard errors clustered at the state,

$$W_{it} = \alpha_0 + \alpha_1 FC_{jt} + \lambda_t + \gamma_i + u_{it} \tag{1}$$

W_{it} denotes groundwater consumption in million cubic meters (mcm) and FC_{jt}, our regressor of interest, is a measure of the fixed cost of electricity in year t and state j. The inclusion of year and district fixed effects allows us to flexibly control for aggregate time shocks such as national agricultural policies and fixed district unobservables such as soil type and hydrogeology.

Our empirical approach uses year-to-year variation in state electricity prices to compare a given district's groundwater demand under various prices controlling for aggregate annual shocks. The identification assumption upon which this approach hinges is that electricity prices are orthogonal to unobserved state-year and district-year determinants of groundwater extraction. However, for a number of reasons discussed below electricity prices might be systematically correlated with unobservables that also impact groundwater use.

First, electricity pricing in India is a potential political tool and as such may reflect election cycles or the importance of the state's agricultural economy, or may be systematically correlated with other state agricultural policies. During our period of study, electricity pricing was often at the discretion of state governments and politicians. It emerged as a political lever in the late 1970s, and has remained a valuable campaign tool through the duration of our sample.[6] Election cycles may also influence other agricultural and energy policies that impact groundwater demand, either directly or indirectly. In fact, a growing literature has empirically tested if elections are systematically related to agricultural lending by publicly owned banks, expenditure on road construction and tax collection, and finds that the provision of many of these goods increased during election years (Cole 2009, Chaudhuri and Dasgupta 2005, Ghosh 2006, Khemani 2004). To account for the possibility that state-year election cycles may be systematically correlated with electricity prices and impact groundwater demand, we include an indicator variable set equal to one if a state-election occurs in a given year.[7]

Generation, and transmission and distribution (T&D) losses may also be correlated with electricity prices and impact groundwater extraction through two channels. First, electricity is often rationed in India so that, at any given price, the quantity of electricity supplied may fall below quantity demanded. Because of this, the available supply rather than the price may be driving groundwater extraction. Prices may also be correlated with generation

[6]The trend between elections and electricity pricing began in Andhra Pradesh in 1977, when the Congress party was the first in India to campaign on the basis of free power. The use of electricity as a campaign tool continued into 2004, the most recent year in our sample, when the Congress Party in Andhra Pradesh campaigned on the ticket of free power (Dubash 2007).

[7]In India, state legislative assembly elections are scheduled every five years. However if the lower parliament finds the state government unfit to rule, the government can issue an election, referred to as a midterm election, prior to the end of the five year term. Recently state midterm elections have become more common, though the frequency of midterm elections varies by state (NIC 2009). If a midterm election occurs, a constitutionally scheduled election will occur five years later. Due to midterm elections, there is substantial variation in electoral cycles across states.

since, with low electricity prices, generation constraints may be more likely to bind. Second, in addition to manipulating electricity prices, state governments may also alter electricity provision through other channels, such as turning a blind eye to electricity theft in certain areas. For these reasons, a failure to control for these variables may confound our estimation of the effect of electricity prices on groundwater demand.

To explicitly control for potential state-year and district-year observables that may confound the estimation of α_1, we augment equation (1) and estimate

$$W_{it} = \alpha_0 + \alpha_1 FC_{jt} + \alpha_2 X_{it} + \alpha_3 X_{jt} + \lambda_t + \gamma_i + u_{it} \quad (2)$$

In the regression, X_{it} denotes district-year rainfall and X_{jt} is a vector of time-varying state observables including whether a state election is held in a given year, annual generation, and transmission and distribution losses. Our identifying assumption in equation (2) is that the inclusion of time-varying state and district observables removes any of the bias present in our simple fixed effects model. More formally, conditional on X_{it}, X_{jt}, λ_t and γ_i, we now assume that electricity prices are independent of potential outcomes. While we cannot directly test this assumption, we later conduct indirect tests that examine its plausibility.

3.2 Agricultural Output

Recall that the intent behind the provision of agricultural electricity subsidies was to increase agricultural output. To test the hypothesis that these subsidies increased agricultural production through the channel of groundwater extraction, we use an instrumental variables approach with standard errors clustered at the state,

$$Y_{it} = \beta_0 + \beta_1 W_{it} + \beta_2 X_{it} + \beta_3 X_{jt} + \sigma_t + \eta_i + \epsilon_{it} \quad (3)$$

$$W_{it} = \alpha_0 + \alpha_1 FC_{jt} + \alpha_2 X_{it} + \alpha_3 X_{jt} + \lambda_t + \gamma_i + u_{it}$$

Our outcome variables V_{it} include log values of agricultural output and log area for total, water-intensive and water non-intensive crops in a district-year. Time-varying district and state observables are defined as in equation (2), and σ_t and η_i denote year and district fixed effects, respectively.

The key parameter of interest β measures the semi-elasticity of agricultural output and the area on which crops are grown with respect to groundwater demand. Our instrumental variables approach restricts the variation in groundwater extraction to that induced by presumably exogenous variation in state-year electricity prices. Our choice to focus on price-induced changes in groundwater extraction is primarily policy driven. It remains largely unresolved as to whether agricultural electricity subsidies had the intended effect of increasing agricultural production through the channel of irrigation, despite this objective serving as the impetus for electricity subsidies. Our empirical approach provides a setting to credibly test the policy question of interest.

4 Data and Descriptive Results

Our empirical examination of the relationship between electricity subsidies, groundwater extraction, and agricultural production relies on three main sources of data: district groundwater data collected by the Central Groundwater Board, annual state electricity data collected by the Council of Power Utilities and annual district agricultural data compiled by the Directorate of Economics and Statistics within the Indian Ministry of Agriculture. We briefly describe these data and their limitations, and begin to examine the plausibility of our main identifying assumption that conditional on fixed district unobservables, year fixed effects and select observables, state-year electricity prices are independent of unobservables.

4.1 Groundwater

District groundwater data obtained from the “Dynamic Ground Water Resources of India”’ reports are available for 280 districts in (a subset of) years 1995, 1998, 2002 and 2004, forming an unbalanced panel of groundwater data for 587 district-years in 13 states. The measurement and definition of annual groundwater extraction in these reports is unique, influencing the interpretation of our results and providing insight into the channel through which electricity prices may alter water usage. Specifically, these reports do not provide physical measures of annual groundwater extraction in a given year. Instead they report a coarse estimate of annual demand based on the “number of abstraction structures multiplied by the unit seasonal draft.” Thus, groundwater extraction in our study captures the number of wells in a given district-year, accounting for specific crop demands, and leads us to interpret changes in groundwater demand as changes along the extensive margin in tubewell installation, adoption and expansion.

Summary statistics on groundwater extraction and recharge are provided in Table 1, where columns 1-3 report these statistics for the entire sample. On average groundwater extraction amounts to 60 percent of recharge. However, this statistic masks the variation in extraction both across districts and over time. Restricting the sample to districts that record groundwater data in 1995 and 2004 reveals that groundwater extraction increased between 1995 and 2004 by 125 mcm or 18.5 percent, though recharge increased as well. Two commonly deployed measures of groundwater over-development - critical and over-exploited - suggest that groundwater exploitation is also increasing over time. Critical indicates that annual groundwater usage is greater than 75% of annual recharge, and provides a signal that groundwater extraction may be approaching unsustainable levels. Within the period examined, 25% of districts move from normal to critical status and 14% move to over-exploited status, defined as a year in which extraction exceeds recharge.

The remaining columns of Table 1 divide the sample based on the median electricity price, and examine whether observables including groundwater demand differ across district-years with high and low electricity prices. A comparison of raw means highlights that annual groundwater extraction is significantly higher in areas with below average electricity prices, providing a first piece of descriptive evidence that electricity rates and groundwater extraction may be inversely related. These differences are no longer significant once we condition on year and district fixed effects, though we cannot discern the extent to which this is driven by the coarse delineation of high and low electricity prices. Later, results using our baseline empirical specification address this possibility by measuring electricity prices continuously.

4.2 Electricity Prices

Data on states' agricultural electricity prices, measured in 1995 Rs per horsepower-month (Rs/hp-mth), were collected for select years between 1995 and 2004.[8] During these years, all states in our sample offered an agricultural electricity rate that was comprised exclusively of a monthly charge, where this charge primarily took the form of a fixed monthly fee per horsepower. On average states charged a fixed fee of 83.5 rupees per hp-month for electricity, though some states such as Tamil Nadu provided agricultural electricity free of charge and others charged rates that exceeded 500 rupees per hp-month. Figure 1 illustrates this cross-sectional variation, as well as the temporal variation in electricity prices that our empirical strategy seeks to exploit. In it, we plot the fixed cost of electricity for all state-years, except Madhya Pradesh in which prices exceed 300 Rs per hp-month in some years.

Two complicating features of agricultural electricity tariffs in India are that a handful of states also offered some customers a volumetric rate and/or structured fixed fees such that the per horsepower cost varied depending on pump size. In approximately 30% of the state-years in our sample, some agricultural users were at least offered a volumetric charge, though we are unable to discern how many users actually opted into these rates. Two observations

[8]Electricity data were gathered from "Tariff Schedules of Electric Power Utilities" which were published in 1997, 1998, 2002 and 2005. In addition to reporting tariffs, these reports record the date that tariffs changed.

lead us to believe that few if any users incurred a volumetric rate. First, between 1995 and 2004 meters for agricultural water use in India were rare due to the high transaction costs involved with installation (Birner et al. 2007).[9] Second, qualitative evidence suggests that few if any agricultural users face a volumetric price for electricity (Banerji et al. 2013).

The presence of tiered rate structures may also complicate our analysis. In approximately 7% of the state-years in our sample, states impose tiered electricity rates, whereby the fixed monthly rate per horsepower varies depending on the size of the pump. Interestingly, we see evidence of both declining and increasing block rates. For customers in states with a tiered rate structure, a change in rates may differentially affect agricultural customers depending on pump size, if for example a rate change is only introduced for one pump size. We address this issue by later testing whether our empirical results are robust to the exclusion of states with a tiered rate structure.

4.3 Agricultural production data

Annual district data between 2000 and 2004 on the value of crop output and crop acreage were provided by the District Agricultural Statistics Portal from the Ministry of Agriculture; summary statistics for the years 2002 and 2004 are reported in Table 1.[10] Total agricultural production is measured as the sum of revenues from wheat, rice, cotton, sugar, maize, sorghum and pearl millet, weighted by the 1995 price for each crop. These crops were chosen because they are prevalent in India, vary substantially in their water intensity and data were available during the period of study. We hold prices fixed at 1995 levels to decouple the effect of price changes from output changes. Water intensive output is measured as the weighted sum of the value of production in rice and cotton and water non-intensive output is comprised of sorghum and millet. A crop was labeled as more or less water intensive

[9] After 2004, some states such as West Bengal introduced metering (Mukherji et al. 2009).

[10] In our analysis, we restrict our sample of agricultural production data to post-2000 since the pre and post-2000 data come from 2 different sources and the pre-2000 data may suffer from measurement issues. During interviews with the head of data collection at the Indian Ministry of Agriculture, she raised multiple concerns with agricultural statistics collected in the mid to late 1990s.

based on its relative level of water inputs, as defined by Hoekstra and Chapagain (2007). As reported in Table 1 water intensive crops account for a large share of agricultural production, generating 44 percent of annual output and accounting for 43 percent of the area cultivated.

A comparison of raw means reveals that the acreage dedicated to water-intensive crops is significantly higher in districts with lower electricity prices, and that the value of non-water intensive crops is higher in areas with high electricity prices. After controlling for fixed district unobservables and aggregate shocks, we find that with the exception of the value of agricultural output, production is balanced across district-years with high and low electricity prices. The value of agricultural output is inversely related to electricity prices, and provides a reduced-form preview of the variation that we later exploit to investigate the effect of subsidy-induced changes in groundwater demand on agricultural production.

4.4 Confounding observables

Isolating the causal effect of a change in the fixed cost of electricity on groundwater extraction could be achieved by simply comparing groundwater extraction across state and years with different electricity prices, if electricity prices were orthogonal to all determinants of groundwater extraction. However, electricity prices may be systematically correlated with district unobservables, aggregate shocks to the economy and state-year unobservables. We also anticipate that demand for groundwater will depend on these factors. Our empirical approach controls for the first two possibilities by conditioning on district and year fixed effects; however it assumes that electricity prices are independent of time-varying unobserved determinants of groundwater extraction. To examine the plausibility of this assumption, we evaluate whether state-year elections, generation, and transmission and distribution losses differ systematically across district-years with high and low electricity prices, using comparisons of unconditional and conditional means, where the latter comparison controls for district and year unobservables.

The differences reported in column 6 of Table 1 make clear the flaws in an empirical approach that relies on a simple comparison of means across states and years with relatively high and low electricity prices. Potentially confounding observables including state-year elections, gross generation, and transmission and distribution losses differ systematically across high and low electricity prices. And while our preferred empirical approach will control explicitly for these observables, one indication that electricity prices may be systematically correlated with unobservables is if they are systematically correlated with observables. To explore the extent to which fixed district unobservables and aggregate shocks explain these systematic differences, in column 7 of Table 1 we present differences in means conditional on district and year fixed effects. With the exception of generation (measured as gross generation in million kWh), the aforementioned observables as well as annual district fertilizer use do not significantly differ across district-years with high and low electricity prices. And while this does not imply that unobservables are balanced across electricity prices, it provides evidence to support the plausibility of our main identifying assumption.

5 Estimation Results

We begin by reporting results from a simple OLS model of demand for groundwater on annual state electricity prices, controlling for fixed district and year unobservables. As shown in column 1 of Table 2, an increase in the fixed cost of agricultural electricity decreases annual district groundwater extraction, where we hypothesize that this reduction in demand occurs along the extensive margin of tubewell adoption and expansion. We find that district demand for groundwater decreases by 0.417 million cubic meters on average with a 1 rupee increase in the price of electricity. This implies that a one standard deviation increase in the fixed cost of electricity would decrease demand for groundwater by 47 mcm or 8.5%.[11] The short-run elasticity of demand for groundwater is approximately -0.07, and fits within the wide range of elasticities, -0.002 to -1.97, reported in a meta-analysis of irrigation water demand

[11] The unit of observation for the electricity statistics in the preceding calculation is the district-year, where the reported mean and standard deviation are 97 and 113 respectively. In contrast, the unit of observation for electricity statistics in columns 1-3 of Table 1 is the state-year

elasticities (Scheierling, Loomis and Young 2006).

As discussed in the estimation strategy, electricity prices may be systematically correlated with time-varying district and state unobservables that impact groundwater demand. And while we cannot rule out this possibility, I examine the robustness of the qualitative relationship between electricity prices and groundwater demand to a number of plausible confounding factors. Results from the augmented OLS are presented in columns 2-6 of Table 2, where column 2 conditions on annual district rainfall and whether or not rainfall is reported in a district-year, column 3 includes an indicator variable denoting whether or not a state-year election occurred, column 4 controls for generation, column 5 includes annual transmission and distribution losses as a covariate, and column 6 includes all the aforementioned time-varying observables as covariates.

Our central finding that electricity subsidies led to an increase in groundwater demand remains after controlling for potential time-varying confounders. The magnitude of the treatment effect is stable across columns 2-5 in which we selectively control for surface water considerations, electoral cycles and potential changes to the electricity supply. Interestingly, conditional on district and year fixed effects, these observables do not meaningfully impact groundwater extraction, perhaps suggesting that district and year fixed effects account for much of the explanatory power that these observables have on groundwater demand.[12]

Results from our preferred specification which conditions on all the time-varying state and district observables suggest an economically stronger though still relatively inelastic effect of electricity prices on groundwater extraction. A one rupee increase in the monthly fixed rate per horsepower of electricity leads to a 1.05 million cubic meter decrease in groundwater extraction. This translates into a short-run price elasticity of -0.18, and is remarkably close to the median elasticity reported in a meta-analysis of irrigation water demand elasticities and recent panel data price elasticity estimates in the High Plains Aquifer (Hendricks and Peterson 2012, Scheierling, Loomis and Young 2006). And while our estimates align with

[12]Simple OLS regressions analogous to those implemented in columns 2-5 except for the exclusion of district and year fixed effects report a statistically significant effect of each covariate on groundwater extraction.

those reported in other studies, we posit that three features unique to the electricity sector in India may explain the low price elasticity. First, the marginal price for agricultural electricity is zero. A change in the fixed fee for agricultural electricity may affect demand along the extensive margin, inducing farmers to install, expand or operate a tubewell, but conditional on operating a tubewell it should not impact electricity demand. Second, electricity shortages may limit customers sensitivity to price changes. Third, a substantial disconnect exists between the magnitude of the subsidies and our observed variation in electricity prices. Our elasticity estimates are based on sizable variation in electricity prices, but this variation is only a fraction of the subsidy amount provided to agricultural users. The limited variation in observed prices relative to the size of the subsidy may dampen the demand response to price changes. While agricultural users are likely to be more responsive to price changes under a regime in which volumetric pricing was introduced, supply side constraints were removed, and electricity was priced at marginal costs, our estimates provide guidance on changes in groundwater demand through the channel of tubewell connections under the status quo pricing regime.

We provide suggestive quantitative and qualitative evidence that changes in the fixed cost of electricity impact groundwater extraction through the channel of tubewell expansion and installation. First, we empirically disentangle the effects of positive and negative changes in electricity tariffs on groundwater use. Our hypothesis is that price changes should primarily operate in one direction, with price decreases leading to a sizable and meaningful increase in groundwater extraction. Indian farmers incur large costs to acquire access to groundwater and it seems unlikely that relatively modest increases in electricity tariffs would induce farmers to discontinue pumping. In contrast, it seems quite plausible that a farmer would choose to install a new well or pump in response to a decline in the flat rate. To examine this possibility, we exclude state-years with price increases in column 7 and price decreases in column 8 of Table 2. Price decreases induce a sizable increase in groundwater extraction whereas price increases lead to a non-significant and comparably modest reduction in groundwater usage. These results suggest that one mechanism through which electricity subsidies impact groundwater extraction is the expansion of tubewells. This hypothesis is more plausible when one considers that the CGWB estimates annual groundwater extraction based on the number of abstraction units in a given district-year.

A separate but related question examines the extent to which these subsidies impact the probability of groundwater over-exploitation, a potential environmental cost attributable to them. Our outcome variables of interest are now indicator variables denoting whether annual district extraction crossed two exploitation thresholds: critical, where annual groundwater usage is 75% of annual recharge, and over-exploited, where usage is greater than supply. Results from the estimation of a linear probability model with district and year fixed effects are reported in Table 3. Our results imply that a one rupee increase in the fixed cost of electricity leads to between a 0.071 and 0.086 percentage point decrease in the probability that a district-year is listed as critical, and a one standard deviation increase in prices induces up to a 9.8 percentage point decrease. We also find a negative but not statistically significant relationship between electricity prices and over-exploitation status, where the absence of explanatory power may be driven by the relatively small number of district-years designated as over-exploited. These results suggest that one unintended cost of these subsidies is the over-extraction of groundwater resources.

5.1 Agricultural production

We estimate the effect of groundwater demand on agricultural production using an IV model and report results in Table 4. In columns 1-3 the dependent variable is the value of total, water intensive and non-intensive agricultural output, and in columns 4-6 the outcome variables are the area on which all, water intensive and non-intensive crops are grown.

Our first stage and reduced form results indicate that electricity prices impact groundwater demand and agricultural output in the expected direction with lower prices increasing both groundwater demand and agricultural output. Estimates from the first-stage mirror those reported in column 6 of Table 2, except that the sample is restricted to the 202 district-years for which agricultural data are available.[13] The corrected F-statistic, reported in Table 4, is 11.7, indicating that the instrument is sufficiently strong in predicting groundwater extraction. Results from the reduced-form relationship between electricity prices and agricultural output are reported in column 7, and show that higher electricity prices lead to an increase in agricultural output.

Electricity-price induced changes in groundwater extraction meaningfully impact both the value of agricultural output and the area on which crops are cultivated. This central result suggests that agricultural electricity subsidies operated through the intended channel of groundwater irrigation to increase agricultural production. The implied elasticity of the value of agricultural output to groundwater usage is 0.60 indicating that output is quite responsive to changes in groundwater use. However, recall that a 5.5 percentage point increase in the fixed cost of electricity is needed to induce a 1 percentage point increase in groundwater demand, so the implied price-elasticity of the value of agricultural output is -0.12.

A second central finding to emerge is that the strong and positive effect of groundwater demand on agricultural output occurs exclusively for water intensive crops. The short-run electricity-price elasticity for water intensive agricultural output is -0.29 and the implied usage elasticity of water intensive agricultural output is approximately 1.4, indicating that the value of agricultural output is highly sensitive to changes in the quantity of groundwater irrigation. In contrast, the value of non-intensive crops actually decreases in response to an increase in groundwater extraction. The juxtaposition of the response of water intensive and non-intensive crops to changes in groundwater extraction suggests that in addition to impacting the value of overall agricultural production, electricity subsidies are also influencing the mix of crops grown.

Turning to columns 4-6, we find that one margin along which farmers are responding to

[13] Recall that due to data quality concerns, we chose to focus exclusively on post-2000 data.

fluctuations in groundwater demand is the area cultivated. An increase in annual groundwater extraction, presumably for irrigation, leads to an increase in the total area dedicated to crop cultivation, where the elasticity of acreage to irrigation is 0.11. This imputed elasticity is consistent with studies in India on the acreage elasticities of agriculture with respect to irrigation (Kanwar 2006). Once we decompose the cultivated area into water-intensive and and non-water intensive crops, we find that this response is primarily driven by water intensive crops. An increase in irrigation causes an expansion in the area on which both water intensive and non-intensive crops are grown, but water-intensive acreage is twice as elastic. This finding provides a second piece of evidence that electricity subsidies are not only increasing agricultural production but also inducing farmers to shift production to water intensive crops.

5.2 Robustness

The robustness of our results hinges on three assumptions: time-varying unobservables that impact groundwater demand are unrelated to electricity prices; electricity prices only impact agricultural production through the channel of groundwater; and a change in the fixed cost of electricity has a uniform effect on the cost per horsepower across all pump sizes. We examined the plausibility of the first assumption in Tables 1 and 2. While we cannot rule out the possibility that time-varying unobservables bias our coefficient estimate on electricity prices, we provide evidence that some potentially confounding observables are balanced across high and low electricity prices. We now propose one check to examine the validity of our instrument, and test the robustness of our results to the exclusion of states with tiered electricity prices.

Our measure of agricultural output captures changes in production gross of other inputs, such as fertilizer. Electricity subsidies may also affect demand for these inputs which in turn may affect agricultural output. Knowing the impact of electricity prices on other agricultural inputs will provide insight into the extent to which electricity subsidies affect the value of agricultural production through channels aside from irrigation. We thus examine the extent to which electricity subsidies influence demand for fertilizer. Table 5 presents results from the estimation of equation (2), except now the dependent variable is annual tons of fertilizer use in a district. Regardless of our measure of fertilizer - all, nitrogen, phosphate or potassium - electricity subsidies do not appear to influence the quantity of fertilizer used, suggesting that the previously reported changes in agricultural production are not capturing a change in fertilizer use. These results do not imply that electricity prices are a valid instrument; instead they provide one piece of evidence that electricity subsidies are not impacting another critical input used in agricultural production.

The robustness of these results also hinges on our measure of electricity prices. One concern is that in states with tiered rates, a change in rates may only impact certain categories of users or may differentially impact customers depending on pump size. To address this possibility, we restrict our sample to state-years in which there is a uniform fixed cost per horsepower regardless of pump size. Table 6 reports results using the restricted sample, where column 1 presents results from an OLS model on groundwater extraction, column 2 presents results from a LPM of the probability that groundwater levels are at a critical level, and columns 3-4 report results from an instrumental variables model in which the dependent variables are total agricultural production and the cultivated area, respectively. The qualitative relationship between the groundwater extraction and electricity prices remains unchanged, though inference on the probability that a resource is over-extracted becomes limited likely due to the small sample size and the relatively infrequent occurrence of critical district-years. We also continue to find that increases in groundwater demand result in economically and statistically significant increases in agricultural production and the area allocated to crop cultivation. These results suggest that the relationship between electricity prices, groundwater extraction and agricultural production is not driven by states with tiered rate structures.

6 Welfare Costs

We now provide a partial approximation of the welfare costs of this policy. The ideal exercise would speak to two costs associated with the existing pricing regime: the absence of volumetric rates for electricity usage, and the subsidies provided to agricultural electricity consumption. Given the difficulty in projecting customer behavior in transitioning from a fixed cost rate structure to a two-part rate structure, we focus our attention on the latter cost. In what follows, we use derived demand for groundwater as laid out in equation (2), specify a long-run marginal cost curve, and then estimate the reduced deadweight loss from a 50 percent reduction in agricultural electricity subsidies. Our partial estimates of the efficiency costs are coarse and provide a back of the envelope measure; nonetheless they serve as a starting point to think about the policy's welfare costs.

We specify a long-run marginal cost curve for groundwater, assuming that it can be approximated using the average unit cost to supply electricity. We combine data collected by the Central Electricity Authority on the average per kWh cost to supply electricity in a state-year with the statistic that a one horsepower irrigation pump uses approximately 200 kWh per month. This provides an average cost of electricity per horsepower-month. We further assume that the long-run marginal cost of electricity is equal to the average cost of electricity in a state-year, and that the electricity supply is infinitely elastic. This latter assumption implies that there is no change in producer surplus from the subsidy.

Driven by concerns about out of sample predictions, we choose to simulate a policy in which we reduce the subsidy by 50%. In the sample for which data on both unit costs and electricity prices are available, the average unit cost per horsepower is 190 Rs/month though farmers on average pay only 55 Rs/month. A comparison of retail prices and unit costs also reveals that there is only one state-year in which the retail price overlaps with the observed unit cost for all state-years in our sample. In contrast, if we model a pricing policy in which we reduce the subsidy by 50% there is substantial overlap across observed and simulated retail prices.

We now calculate the efficiency gain from a 50 percent reduction in the state level subsidy as,

$$p^o(GW(p^e) - GW(p^o)) - \int_{GW(p^o)}^{GW(p^e)} p(GW)dGW \tag{4}$$

Prices denoted by p^e and p^o reflect the current price of electricity and the price associated with a 50% reduction in the electricity subsidy, and are measured as the fixed monthly per horsepower price in a state-year. Groundwater extraction, $GW()$, is the estimated quantity of groundwater extraction in a given district-year at price p and is estimated using equation (2).

Given the price inelasticity of demand in the short-run and the assumption that the electricity supply is infinitely elastic, the partial efficiency loss associated with a reduction in the subsidy on fixed fees for electricity is small. It amounts to 9 paise for every rupee spent on electricity subsidies. The efficiency losses would almost certainly be larger if our welfare analysis also incorporated existing distortions in the sector, including the absence of marginal pricing for electricity, rationed electricity supplies, and the magnitude of the subsidy. For these reasons, we view our results as a first step in understanding the welfare costs of these subsidies.

7 Conclusion

Despite the magnitude of agricultural electricity subsidies in India, both in absolute and relative terms, and the controversy surrounding them, little is known about their causal impact on groundwater resources and agriculture. This study aims to inform this discussion by isolating their impact on groundwater extraction and over-exploitation, and agricultural output. Using detailed district panel data we find that this policy increased groundwater extraction through the channel of tubewell adoption and expansion, and had meaningful agricultural implications both in terms of the value of agricultural output and crop composition. Our results reveal an extensive margin price elasticity for groundwater demand of

-0.18. They also show that subsidy-induced increases in groundwater extraction led to an increase in the value of water-intensive agricultural production and the area on which these crops are grown.

These findings provide some of the first empirical evidence that agricultural electricity subsidies indeed achieved the intended objective of increasing agricultural production through the channel of irrigation. Under certain assumptions and holding constant other existing distortions in the electricity sector, they also suggest that this policy was relatively efficient at transferring government expenditure. The efficiency losses from this subsidy amount to 9%, though our analysis remains silent on the costs incurred from imposing a rate structure comprised exclusively of fixed monthly fees for electricity. This consideration is of relevance given the passage of the Electricity Supply Act of 2003 which mandates metering for all categories of electricity users.

While these subsidies encouraged groundwater irrigation and increased agricultural production, they may come at a real and long-term environmental cost. There is substantial concern in India over the over-exploitation of groundwater resources and the sustainability of India's current extraction patterns. Our results suggest that electricity subsidies have contributed to groundwater over-exploitation, where we predict that a one standard deviation decrease in electricity prices will lead to a 10 percent increase in the probability that groundwater resources are listed as critical. They point to a potentially longer-run cost of electricity subsidies if current patterns of groundwater extraction compromise the quantity and perhaps quality of groundwater resources available for future use.

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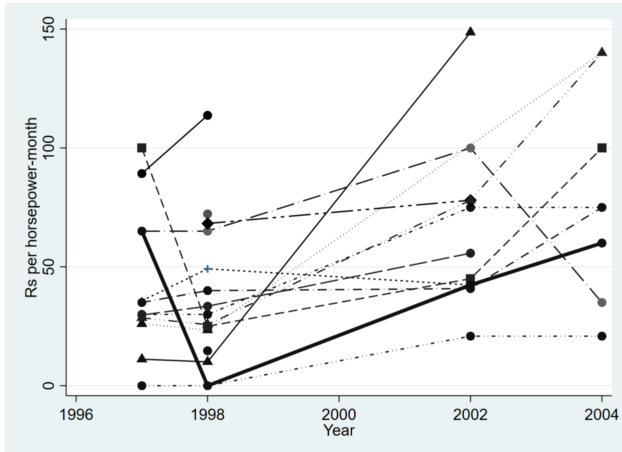

Figure 1: State Electricity Prices by Year, Excluding Prices> 300 Rs

Table 1: Summary Statistics: Groundwater and agricultural output

	Mean	SD	Obs	Mean by elec price		Difference in means	
				<65 Rs	>65 Rs	Unconditional	District, Year FE
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
District-Year Variables							
GW extraction (mcm)	582	509	587	616	546	70*	52
GW recharge (mcm)	952	579	587	959	945	15	41
Value agriculture (million 1995 Rs)	2,441	2,729	583	2,244	2,644	401*	554**
Value H20 intense	1,079	1,515	577	1,070	1,090	20	96
Value non-H20 intense	144	290	575	112	178	66***	48
Area crops grown (1000 hectares)	290	187	451	302	282	20	6
H20 intense area	124	118	451	137	115	23**	2
Non-H20 intense area	57	109	451	50	63	13	5
Fertilizer applied (tons)	36,534	30077	382	35,189	37,827	2638	3007
State Variables							
FC electricity (Rs per hp-mth)	83.5	117	60	39	159	120**	73*
Generation (million kWh)	19,263	10,621	56	23,122	19,176	3946***	3352**
T & D losses (million kWh)	29	9	60	27	34	8***	2.4
Election year	0.18	0.39	50	0.52	0.07	0.4***	0.32

Notes: The table reports means, standard deviations and counts for district-year and state-year variables. Columns 4-5 report means for district-years in which electricity prices are less than and greater than the median. Column 6 reports the absolute value of the unconditional difference in means and column 7 reports the absolute value of the difference conditional on year and district fixed effects with standard errors clustered at the state. Asterisks indicate significant differences in means; ***p<0.01,**p<0.05,*p<0.1.

Table 2: OLS models of demand for groundwater

Demand Groundwater	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Fixed Cost Electricity	-0.417**	-0.499	-0.402**	-0.513*	-0.578*	-1.054*	-3.214	69.78*
	(0.201)	(0.528)	(0.188)	(0.279)	(0.337)	(0.582)	(4.805)	(40.07)
Rainfall		-152.5				-202.6**	-204.3**	331.8
		(113.0)				(81.35)	(98.28)	(221.3)
Rainfall Reported		-1,583				-2,054**	-2,103**	5,691*
		(1,202)				(815.5)	(1,007)	(3,163)
State-Year Election			-32.37			-39.44	-30.61	
			(62.71)			(64.28)	(75.29)	
Generation				-0.00429		-0.00724	0.00209	
				(0.00642)		(0.00915)	(0.0112)	
T&D Losses					5.17	13.49	11.84	
					(6.177)	(8.992)	(8.362)	
Fixed effects	district	district	district	district	district	district	district	district
	year	year	year	year	year	year	year	year
Observations	587	587	587	587	587	587	533	149
R-squared	0.913	0.917	0.913	0.913	0.914	0.921		

Notes: The dependent variable is the quantity in million cubic meters of groundwater extracted in a district-year. Columns 1-8 report results from an OLS model with standard errors clustered at the state in parentheses. Columns 7 and 8 exclude state-years in which prices decreased and increased, respectively. Asterisks denote significance; *** p<0.01, ** p<0.05, * p<0.1

Table 3: Linear probability model of groundwater exploitation

GW Development	(1) Critical (75%)	(2) Exploited (100%)	(3) Critical (75%)	(4) Exploited (100%)
Fixed Cost Electricity	-0.000708***	-0.000405	-0.000855***	-0.000495
	(0.000216)	(0.000547)	(0.000259)	(0.000497)
Rainfall			0.100	0.161
			(0.0899)	(0.108)
Rainfall Reported			1.099	1.827
			(0.925)	(1.138)
State-Year Election			-0.0986***	-0.00484
			(0.0177)	(0.0654)
Generation			-1.65e-05**	-8.23e-06
			(7.45e-06)	(1.03e-05)
T&D Losses			-0.00283	0.00298
			(0.00256)	(0.00884)
Fixed effects	district	district	district	district
	year	year	year	year
Observations	593	593	593	593
R-squared	0.805	0.804	0.813	0.821

Notes: The dependent variable is an indicator variable set equal to 1 if groundwater extraction is 75% or 100% of annual groundwater recharge. Columns 1-4 report results from an OLS model with standard errors clustered at the state in parentheses. Asterisks denote significance; *** p<0.01, ** p<0.05, * p<0.1

Table 4: IV model of agricultural production

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Value Agricultural Output			Area Cultivated			Output
	Total	H20 Intensive	Less Intensive	Total	H20 Intensive	Less Intensive	Total
Groundwater Demand (mcm)	3.110***	3.261***	-0.0736**	60.58***	24.79**	5.823*	
	(0.460)	(0.426)	(0.0301)	(18.68)	(10.94)	(3.068)	
Fixed Cost Electricity							-3.158
							(2.156)
Ag-Water Elasticity	0.602	1.42	-0.198	0.119	0.117	0.0551	
Fixed effects	district	district	district	district	district	district	district
	year	year	year	year	year	year	year
Observations	202	200	202	202	202	202	202
F-stat	11.7	11.3	11.7	11.7	13.8	11.7	

Notes: The dependent variable is agricultural output (measured in millions of Rs) in cols. 1-3 and hectares cultivated in cols. 4-6. Columns 1-6 report results from an IV model in which electricity prices serve as an instrument for groundwater extraction. Column 7 reports results from the reduced form regression of agricultural output on electricity prices. Additional controls include generation, transmission and distribution losses, annual rainfall, rainfall reported and the presence of a state election. Standard errors clustered at the state are in parentheses. Asterisks denote significance; *** $p<0.01$, ** $p<0.05$, * $p<0.1$

Table 5: OLS model of demand for fertilizer

Fertilizer Use (Tons)	(1) All	(2) Nitrogen	(3) Phosphate	(4) Potassium
Fixed Cost Electricity	-11.12	3.044	-4.232	-9.934
	(44.52)	(21.18)	(15.04)	(17.36)
Rainfall	-331.7	-519.0	652.4	-465.1
	(4,933)	(3,252)	(1,438)	(906.7)
Rainfall Reported	-3,881	-6,282	6,494	-4,094
	(50,983)	(33,901)	(14,690)	(9,292)
State-Year Election	5,089	2,012	1,396	1,682*
	(4,212)	(2,358)	(1,274)	(880.2)
Generation	-0.401	0.0516	-0.232	-0.221
	(1.401)	(0.715)	(0.462)	(0.487)
T&D Losses	218.1	166.8	55.58	-4.298
	(580.9)	(304.3)	(183.7)	(185.9)
Fixed effects	district	district	district	district
	year	year	year	year
Observations	382	382	382	381
R-squared	0.975	0.974	0.968	0.977

Notes: The dependent variable is the quantity of fertilizer applied in a district-year. Columns 1-4 report results from an OLS model with standard errors clustered at the state in parentheses. Asterisks denote significance; *** p<0.01, ** p<0.05, * p<0.1

Table 6: Robustness test: Exclusion of states with tiered rate structure

	(1)	(2)	(3)	(4)
	Groundwater Demand	Critical (75%)	Agricultural Output	Cultivated Area
Fixed Cost Electricity	-1.656**	-0.000940		
	(0.745)	(0.000806)		
Groundwater Demand			14.82**	283.5**
			(6.958)	(133.9)
Rainfall	-201.3***	0.0973	1.108	0.350
	(54.47)	(0.0887)	(0.930)	(0.311)
Rainfall Reported	-2,097***	1.076	9.559	3.029
	(549.8)	(0.918)	(8.922)	(2.996)
State-Year Election	-46.53	-0.100***	-0.468***	-0.172***
	(45.60)	(0.0234)	(0.172)	(0.0619)
Generation	-0.000704	-1.63e-05	0.000143	4.05e-05
	(0.00721)	(1.50e-05)	(0.000151)	(5.32e-05)
T&D Losses	11.81**	-0.00279	0.523**	0.179**
	(5.665)	(0.00406)	(0.239)	(0.0853)
Fixed effects	district	district	district	district
	year	year	year	year
Observations	546	551	162	162
F-stat			4.05	4.05

Notes: The dependent variable is reported in each column heading. The sample is comprised exclusively of state-years where the price per hp-mth of electricity is uniform across pump size. Columns 1-2 report results from an OLS model and columns 3-4 report results from an IV model. Standard errors clustered at the state are in parentheses. Additional controls include generation, transmission and distribution losses, annual rainfall, rainfall reported and the presence of a state election. Asterisks denote significance; *** p<0.01, ** p<0.05, * p<0.1