Can Electricity Pricing Save India's Groundwater? Field Evidence from a Novel Policy Mechanism in Gujarat

Ram Fishman, Upmanu Lall, Vijay Modi, Nikunj Parekh

Abstract: Efficient pricing of water and energy, advocated by economists as a means of achieving more efficient allocations, is often politically infeasible, especially in developing countries. In India, for example, subsidized, nonvolumetric pricing of the electricity used to pump groundwater is politically entrenched and often blamed for groundwater depletion. Are there politically feasible ways to introduce incentives for conservation? We worked with a state government to design and test an alternative, voluntary approach, that invites farmers to install electricity meters and receive compensation for every unit they "save." Interest in participation was high, leading to an unprecedented voluntary shift to meter-based billing, but we found no impacts on water usage. These results provide some of the first empirical evidence on the effect of incentives on water use in India, and we discuss the extent to which they are informative about other policy tools, such as full pricing.

JEL Codes: Q12, Q25, O29, Q38, Q48

Keywords: Agriculture, Energy, Irrigation, Pricing, Scarcity, Water

GROWING DEMAND FOR FOOD, and therefore for irrigation water, is placing increasing pressures on finite, depleting water resources in many parts of the world (Vörösmarty et al. 2000), and the resulting scarcity is threatening to undermine the livelihood of hundreds of millions of smallholder farmers in semi-arid developing countries. Water withdrawals are also associated with substantial use of energy for pumping. Improvements in the efficiency of allocation and usage of these resources can help alleviate scarcity, but realizing these potential improvements remains a major policy challenge.

Ram Fishman (corresponding author) is at the Department of Public Policy, Tel Aviv University, and Department of Economics, George Washington University (ramf@post.tau.ac.il). Upmanu Lall is at the Columbia Water Center, Columbia University. Vijay Modi is at the Department of Mechanical Engineering, Columbia University. Nikunj Parekh is at the Columbia

Received September 24, 2014; Accepted July 4, 2016; Published online November 3, 2016.

JAERE, volume 3, number 4. 2333-5955/2016/0304-00XX$10.00 http://dx.doi.org/10.1086/688496

Economic theory suggests that the marginal (volumetric) pricing of water at its full social cost (shadow price), which would include the cost of energy for pumping, will result in efficient allocations and may slow down water resource depletion (to the extent that it is inefficient). The full pricing of water is therefore often advocated as a policy prescription (World Water Commission 2000; Rogers, de Silva, and Bhatia 2002).

However, in practice, and especially in developing countries, water resources do not have clear property rights and their allocation is constrained by a host of political, institutional, and technical barriers. As a result, water withdrawals are often neither regulated nor priced (Tsur and Dinar 1997; Johansson et al. 2002) and are determined through "second-best" mechanisms such as quotas or nonvolumetric pricing (Johansson et al. 2002). While efficient distribution of power could help control water extraction (Scott and Shah 2004), energy use is also commonly distorted by widespread subsidies in rural areas of developing countries (Morgan 2008).

In light of these political constraints, a natural question is whether there exist indirect, politically feasible ways of introducing marginal incentives for conservation of water (and power) that can result in more efficient allocations. This paper discusses one such approach and reports an evaluation of a pilot program recently undertaken in the Indian state of Gujarat, where groundwater resources have been mined for decades through intensive use of subsidized electricity.

Globally, about 40% of irrigation water is supplied from groundwater, and India is the world's largest user, with 70% of agricultural production and more than 50% of the population depending on it (World Bank 1998; Shah 2010). The common-pool nature of groundwater and the difficulty of observing it directly make this resource especially difficult to monitor and regulate (Mukherji and Shah 2005; Aeschbach-Hertig

Water Center, India. This research was supported by the Harvard Kennedy School Sustainability Science Program and by the Columbia Water Center. We thank Principal Secretaries of Energy for the Government of Gujarat (former), Mr. D. J. Pandian and Mr. S. Jagdishan, and (former) directors of the North Gujarat Electricity Utility (UGVCL), Mr. N. Srivastava and Mr. A. K. Verma. This work would not have been possible without the support of Sahil Gulati, Anil Kumar, Sandeep Mahajan, Kapil Narula, Dishant Patel, Ankur Patel, and Shama Praveen of the Columbia Water Center. The paper has benefited from comments by Avinash Kishore, Michael Kremer, Sebastian Morris, Rohini Pande, Tushaar Shah, Shilp Verma, and participants of the Governance Innovations for Sustainable Development seminar at the Harvard Kennedy School, seminars at the Trachtenberg School of Public Policy and the Elliot School of International Affairs at George Washington University, the World Bank Fund Environment and Energy Research seminar, the World Bank South Asia seminar, and the eleventh annual meeting of the International Water Resource Economics Consortium (IWREC), World Bank, Washington, DC. We are also grateful for invaluable suggestions of two anonymous reviewers.

and Gleeson 2012), and in many parts of the world, groundwater resources are being depleted because of unsustainable extraction levels in excess of natural recharge rates (Wada et al. 2010; Famiglietti 2014). The rates of depletion in India are probably the world's highest (Livingston 2009; Rodell, Velicogna, and Famiglietti 2009; Tiwari, Wahr, and Swenson 2009; Fishman 2011; Aeschbach-Hertig and Gleeson 2012), and by some estimates, 20% of India's electricity supply is used for pumping groundwater. In 2008, the Indian government estimated that there were 15 million electrical pump sets (agricultural consumers) on the grid (fig. 1).

Subsidies on power for pumping groundwater are thought to play a central role in the Indian groundwater crisis (Badiani, Jessoe, and Plant 2012; Badiani and Jessoe 2013). The great majority of agricultural power consumers in India (who use it almost entirely for pumping groundwater) are unmetered, and if they are charged at all, are billed a flat, nonvolumetric, and highly subsidized tariff proportional to the power of the pump (table 1). The origin of the flat rate system dates back to an attempt in the 1970s to reduce the transaction costs of metering and volumetric billing, but it has since become entrenched by political dynamics that saw the actual level of the flat

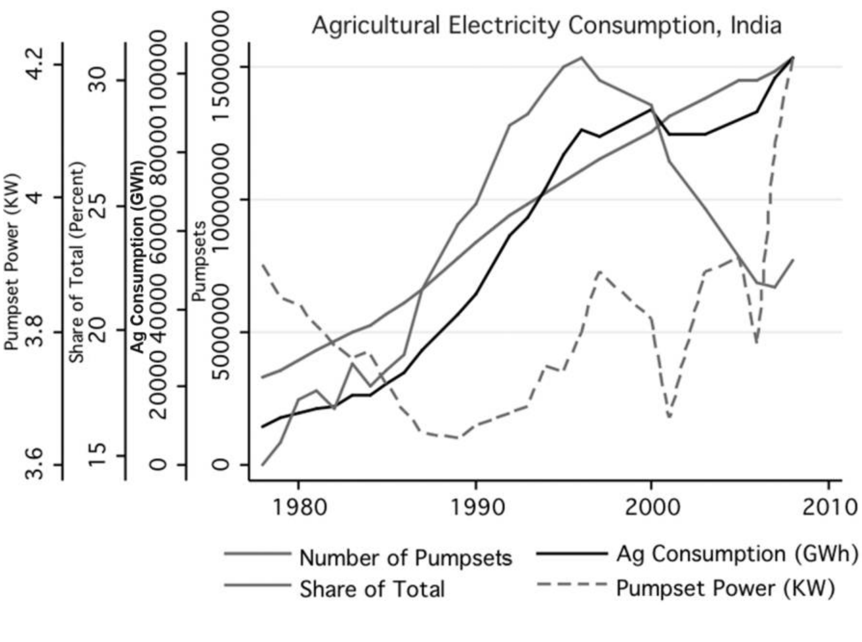

Figure 1. Number of electrical pump sets (*light gray*), agricultural electricity consumption (in GwH, *black*), as a share of total electricity consumption (percentage, *gray*), and the average pump set power (KW, *gray dashed*) from 1978 to 2008. Source: All India Electricity Statistics, annual volumes.

Table 1. Characteristics of the Agricultural Power Sector across Indian States

	UGVCL	GJ	AP	HR	KA	MH	MP	PB	RJ	TN	UP	India
Electrified pumps (1,000)****	200	911	2,681	526	1,729	3,013	1,355	1,033	910	1,990	898	14,136
Number of consumers (100,000)****	30	118	231	47	181	194	91	73	92	222	127	1,376
Fraction of sown area irrigated by GW(%)**		30	19	62	12	11	16	61	23	22	50	
GW dependent cultivators*****		1,698	1,439	882	4,140	1,405	1,190	326	7,884	1,081	4,782	24,826
Electrically powered wells**	200	568	1,692	254	807	1,594	1,368	789	510	1,413	487	9,680
Agricultural electricity consumers (1,000)***		840	2,441	474	1,705	2,778	1,350	966	801	1,920	875	14,310
Average agricultural tariff (Rs/unit)****		1.77	.09	.36	1.45	1.97	2.29	.00	1.21	.00	2.10	1.05
Average overall tariff (Rs/unit)****		4.06	2.61	3.38	3.38	4.32	3.12	2.55	3.05	3.29	2.90	3.18
Cost of power supply (Rs/unit)****		5.14	4.01	4.41	6.62	5.58	4.77	4.51	3.30	4.14	6.80	4.91
Agricultural power subsidy (Rs. 10 million)****		3,049	4,868	3,122	3,280	2,928	2,190	4,054	3,024	4,422	1,526	32,464
Agricultural subsidy/Total gross subsidy (%)****		90	85	88	90	75	79	83	78	59	34	
Surplus from other users/Total gross subsidy (%)****		34	30	3	42	31	−15	−10	−12	29	−16	
Uncovered subsidy /Total gross subsidy (%)****		34	21	33	10	69	92	52	80	52	76	

Sources. ** = 3rd Minor Irrigation Census 2001; *** = All India Electricity Statistics, 2008; **** = Planning Commission (2011); ***** = Calculated by multiplying the total number of cultivators (2011 Indian Census) with row 5.

Note. Column 1 reports data from the area served by UGVCL, the Northern Gujarat utility company. Other columns report data for various other groundwater intensive states, starting from Gujarat and ending with national level figures. GJ = Gujarat, AP = Andhra Pradesh, HR = Haryana, KA = Karnataka, MH = Maharashtra, MP = Madhya Pradesh, PB = Punjab, RJ = Rahasthan, TN = Tamil Nadu, UP = Uttar Pradesh.

rate drop over time, to the point of becoming completely nullified in some states (Dubash and Rajan 2001, 2002; Shah et al. 2008). It is widely believed that the distorted incentives associated with this flat tariff are responsible, at least in part, for inefficient usage[1] and excessive withdrawals of groundwater (Dinesh Kumar and Singh 2001; Kumar 2005; Planning Commission 2012). However, while Badiani and Jessoe (2013) show that the level of the flat tariff affects groundwater extraction, there is little empirical evidence on the impact the flat rate system itself vis-à-vis volumetric pricing.

Agricultural power subsidies are also thought to be responsible for the poor financial situation of most public power utilities in India (Reddy and Sumithra 1997; Dubash 2007; Planning Commission 2012). However, despite the consensus that the supply of power to agriculture should be reformed, all attempts to reinstate full electricity pricing in groundwater-scarce parts of India have been foiled by political resistance (Dubash and Rajan 2001, 2002), and the Indian Electricity Act, 2003, which calls for universal metering of all consumers, remains unenforced by most state governments. As a result, state governments have few politically feasible policy tools by which to contain the groundwater and power crises,[2] other than the rationing of power supply (Shah, Giordano, and Mukherji 2012), and there is little empirical evidence by which to assess what the impact of marginal pricing in groundwater-scarce areas might be.

The approach studied in this paper attempts to circumvent the political difficulty of restoring full volumetric pricing by following a voluntary approach. Well owners were invited to have meters installed on their pumps and to receive compensation per unit reduction of electricity use below a benchmark "entitlement." Usage above the baseline would not be charged. The voluntary nature of this approach and the lack of any impositions on farmers' water usage can make such an approach more acceptable to well owners than one based on regulation or direct pricing, while still introducing a marginal opportunity cost to the use of electricity (and hence groundwater) that could create an incentive for greater efficiency and potentially decrease demand. To succeed, however, the program needs to: first, generate a high rate of take up, which is not obvious in the Indian context because of deep suspicions that metering of power will be used by electric utilities to eventually charge farmers the full costs; and second, improve the efficiency of water and power use to an extent that outweighs any potential losses resulting from its design, including the difficulty of determining accurate baselines, which can discourage behavior change and lead to unwarranted compensation (more below). For both reasons, the performance of the program is a matter for empirical evaluation.

It is important to note that while the program targets electricity use, it aims to introduce efficiency to both electricity or groundwater use and potentially to reduce us-

1. For example, according to the 3rd Minor Irrigation Census, the great majority (about 95%) of Indian farmers flood their fields through open channels (Ministry of Water Resources 2001), a method of water applications which is prone to large evaporation losses.

2. Sekhri (2012) evaluates some recent policy attempts to contain groundwater withdrawlas.

age of both of these inputs (direct regulation of water is practically impossible). For a given water table depth and pumping infrastructure, power and groundwater use are directly proportional, so the two objectives are directly related. We will therefore be referring to electricity or water use interchangeably throughout the paper.

The basic idea of providing well owners with an entitlement to their current energy usage and allowing them to sell or trade it has been proposed before (Morris 2001),[3] but as far as we are aware, has never been tested in the field. In the pilot reported here, "trade" was limited to receiving compensation for reduced usage, which amounts to selling power back to the state. Future expansions could also allow consumers to exceed their entitlement level but to be fully billed on a per unit basis or to sell power to other agricultural or nonagricultural consumers. The program could be thought of as a gradual step toward transforming the power subsidy into a direct cash subsidy, an approach increasingly being considered by the government of India in other domains.

In some ways, the program is similar to energy conservation rebates commonly used in industrialized countries to incentivize reductions in usage in lieu of full pricing (Wolak 2010; Ito 2013) and it shares some of their weaknesses (see below). It is also somewhat akin to the increasingly popular approach of payments for ecosystem services in which participants are rewarded for complying with behaviors that are protective of the environment (Jack, Kousky, and Sims 2008). However, in this context, the incentive is only one part of an attempt to address deeper energy market failures, common in developing countries, by introducing metering and, in a sense, property rights, to an institutional void surrounding agricultural electricity use.

After discussing challenges to the design and implementation of the program, we present an evaluation of a field implementation that took place in the state of Gujarat in 2012. Contrary to the prevailing opinions among officials and bureaucrats with whom we discussed the program, we found a high degree of interest among well owners to join the program (75%) and no indications of attempts to tamper with meters. We believe this was the first instance of successful voluntary metering and volumetric billing of agricultural consumers in India in decades. The program's impact on electricity and water use, however, was less encouraging.

Estimating the program's impact on energy use was complicated by the nature of the intervention, since untreated consumers' electricity use is not metered. Our first empirical strategy exploits the availability of aggregate time-series data on electricity use at the feeder (a node of the electricity grid) level through a difference-in-difference estimate. Our second empirical strategy made use of special devices that measure the duration of pump operation and were welcomed by both treated and control consumers, probably because they did not clearly indicate actual electricity usage in kilowatt hours (KwH), but rather in hours. We did not find any evidence of reductions in demand for

3. Similar ideas are expressed by Gulati (2011) and Krishna (2012).

electricity (or shifts in irrigation practices) using either estimation strategy, and we are able to statistically bound the impacts at well below the level of impact that was anticipated by the officials we discussed the pilot with. Substantial rebates were made to many of the participating well owners, but our estimates suggest these rebates were a result of inaccuracies in the determination of baselines (i.e., counterfactual usage), an unavoidable weakness of programs of this kind (Ito 2013). Interestingly, our estimated impact on actual electricity usage, based on physical measurement, is at odds with the positive treatment effect that would be inferred on the basis of well owners' self-reports of their energy and water use. This highlights the potential pitfalls of relying on self-reported behavior, prone to strategic reporting, in evaluating programs of this kind.

We conclude the paper by discussing several possible explanations for the lack of observed response by well owners and what general lessons can be learned from this study. We are able to rule out lack of understanding or trust of the government's intent to compensate reductions in energy use, since an abnormally abundant monsoon rainfall at the start of the program led to reduced demand for irrigation water, and this "saving" of electricity (which was not due to any intentional effort by well owners) led to compensations being transferred to the majority of well owners in our sample. Instead, we hypothesize, on the basis of qualitative interviews of well owners, that a combination of social norms governing trade in water and lack of familiarity with low-cost water-saving technologies is responsible for these results.

Nevertheless, we acknowledge that factors related to the general nature of the mechanism, as well as some that are specific to the pilot and the study area could also be driving our results. We therefore caution against reaching sweeping conclusions regarding agricultural energy pricing in India on the basis of this study and call for additional field experiments in a variety of locations and designs to fully assess the potential of this particular policy approach.

This paper contributes to the growing literature on the political economy of the Indian groundwater crisis.[4] It also contributes valuable field evidence to the ongoing dis-

4. A growing empirical literature is exploring the political economy of the Indian groundwater crisis (see Badiani et al. [2012] and Shah et al. [2012] for reviews). For example, Sekhri and Nagavarapu (2013) find evidence that regulatory capture of electricity regulation amplifies groundwater extraction. Highly relevant to this paper are studies that find groundwater usage is sensitive to energy pricing. Badiani and Jessoe (2013) find that higher levels of subsidy (lower levels of the flat tariff) lead to increased groundwater extraction and the cultivation of water-intensive crops. Kumar (2005) conducts simulations, based on primary data from Gujarat, that suggest that volumetric pricing of energy would reduce demand for groundwater. In a study closely relevant to this paper, Mukherji et al. (2009) and Meenakshi et al. (2012) investigate the impacts of shifts to marginal electricity pricing in West Bengal, a groundwater-abundant state. They find little evidence of reductions in groundwater use, but some effects on water markets.

cussion of water and energy pricing and subsidization in rural areas of developing countries. While abolishing energy and water subsidies in developing countries is often advocated on grounds of economic efficiency (IEA 1999; Bacon and Besant-Jones 2001), few field studies have explored the success and implications of attempts to implement such reforms (Mukherji et al. [2009] is an exception).

Section 1 describes the program under evaluation and conceptually discusses some challenges in its design and implementation. Section 2 describes the study area, the implementation of the pilot, and the experimental design. Section 3 outlines the empirical analysis and the results. Section 4 discusses some possible explanations for the observed results and what general lessons, if any, can be learned from them. Section 5 explores directions for further research and concludes.

1. PROGRAM DESIGN

From 2010 to 2013, we worked with the Columbia Water Center (CWC), the Government of Gujarat (GoG) and the North-Gujarat Electrical Utility (UGVCL) to design and pilot an incentive scheme that introduced voluntary metering and rewarded participating UGVCL agricultural consumers for reductions in electricity usage below a baseline endowment. Agricultural consumers of UGVCL are groups of one or more farmers (see below) who co-own a well and a pump that is connected to the grid and billed by UGVCL. These agricultural consumers form the unit of our analyses, and we will refer to them simply as "consumers" in the remainder of the paper. As noted above, the scheme targets electricity use but seeks to influence the usage of both groundwater and the electricity used for pumping it, which are directly related to one another. In this section, we describe the details of the compensation scheme that was eventually chosen by the GoG and UGVCL.

1.1. The Rate of Compensation

Economic efficiency dictates that the rate of compensation per unit "saved" by the consumer be set at the social shadow price that includes the cost of electricity generation and delivery as well as the scarcity value of groundwater (Johansson et al. 2002). However, from the narrower point of view of the utility, revenue neutrality dictates that the rate of compensation be set no higher than the marginal cost of power supply or the rate at which it sells electricity to nonagricultural consumers (assuming the electricity "saved" by agricultural consumers can be sold to these other consumers). The GoG took a conservative approach and set the rate at 2.5 Rs. per unit (KwH) of electricity. This rate is lower than the cost of power supply (the statewide cost of power supply is about 5 Rs.) and the rate paid by nonagricultural consumers (commercial and industrial consumers pay close to 6 Rs. per unit, table 1). On the other hand, it is higher than the mean water price in the informal water markets that are prevalent in the area, suggesting that this rate might still be high enough to generate a response among participating consumers (fig. 7).

The GoG wanted to avoid direct monetary transfers to consumers. Instead, it compensated them through reductions in their bimonthly flat rate power bills. UGVCL charges its agricultural consumers a flat rate, proportional to the power of their pump, worth about 20% of the value of the typical electricity consumption, if priced at 2.5 Rs/unit. In effect, this put a cap of 20% on the amount of saved electricity for consumers that could be rebated.

1.2. Baseline Entitlements, Additionality, and Selection

Subsidy programs that reward prosocial behavior often suffer from the difficulty of predicting counterfactual behavior in the absence of the program and, therefore, possibly rewarding behavior that is not additional. The problem of additionally has been widely discussed in the literature of pro-environmental incentive programs, including in the context of deforestation (Sánchez-Azofeifa et al. 2007; Pfaff, Robalino, and Sanchez-Azofeifa 2008; Alix-Garcia, Shapiro, and Sims 2012), carbon emissions (Schneider et al. 2007), and energy efficiency programs (Ito 2013; Boomhower and Davis 2014).

In our context, the problem is rooted in the difficulty of determining baseline entitlements that accurately reflect existing usage or predict future usage. Estimating these baseline entitlements is complicated by variation over time and across consumers in electricity usage, as well as the fact that prior to the program, consumers were not metered, so data on past usage are not available. The determination of baseline entitlements is therefore a challenging aspect of program design, as any inaccuracies can result in rebates being made to consumers whose entitlements are overestimated, even if they do not reduce their usage, and vice versa, in transfers not being made to consumers who make a genuine effort to reduce usage but whose entitlements are underestimated. The problem could be further exacerbated by increased selection into the program by consumers whose entitlements are overestimated, especially if participation is perceived as costly by consumers. In an extreme scenario, all participants could be of this type, and if they do not change their usage, all rebates can be inframarginal. As will be seen below, we did not find evidence of self-targeting into the program by low electricity users. However, inaccurate baseline entitlements will still introduce additional costs to the policy maker. Whether these costs are large enough to overturn the program's benefits is an empirical question.

Three basic approaches to determining entitlements were considered in the course of the program's design.[5]

---

5. This discussion ignores issues of fairness and equity in determining the distribution of entitlements and focuses on approximating the current distribution of power in order to ensure the attractiveness of the program to existing consumers. Several authors claim that the power subsidy disproportionally benefits larger landowners. In contrast, Mukherji (2007) claims that high flat rate tariffs have actually benefited smallholders by providing them access to groundwater through informal water markets with relatively low marginal water rates. This raises the con-

1.2.1. Measuring Usage

To determine accurate baselines, a possible strategy could be to begin the scheme with a certain period of metering (ideally a year) during which no compensation would be made. However, it might be difficult to recruit suspicious consumers to the program in this way. Moreover, this approach introduces serious concerns about strategic behavior on the part of consumers, especially when the program is gradually expanded, and actual usage may well fluctuate from year to year as a result of changes in weather and other factors. This approach was therefore determined to be impractical.

1.2.2. Landholding-Based Entitlements

Energy usage for irrigation can be written as $E = \lambda \times L$, where L is the landholding size, and λ is a parameter that measures the amount of energy used to pump water per unit area of owned land and incorporates the fraction of irrigated area, water application rates, and the energy required to lift a certain amount of water to the surface (a function of the pumping infrastructure and local hydrogeology). Landholding sizes are observable from land records (even if somewhat outdated), but λ is unobservable and likely to vary across consumers. Baseline entitlements could be determined by multiplying landholding sizes with a regional average value of λ that can potentially be estimated on the basis of regional hydrogeology and cropping patterns.

1.2.3. Pump-Capacity-Based Entitlements

Energy usage for irrigation can be written as $E = T \times \mathrm{HP}$, where T is the annual duration of water pumping and HP is the capacity (in horsepower) of a consumer's pump.[6] Since utilities often charge consumers a pump-capacity-based flat tariff, HP is known to the utility, and in any case, is also easy to verify in the field with relative ease. However, the actual duration of power use is unobservable (prior to the program) and may differ across consumers. Baseline entitlements could be determined by multiplying observable HP values with a average value of T that could be calculated from aggregate consumption data (see below).

The GoG decided to follow the third approach, because it was thought that variation in T is likely to be lower than variation in λ, as all UGVCL agricultural con-

---

cern that the mechanism discussed here might also affect local water markets and potentially harm water buyers, who do not own their own wells or electrical connections. These water-buying farmers may face increasing water rates or reductions in sales but will not receive any power entitlements and become worse off. Some evidence from West Bengal, a groundwater-abundant state, where metering of agricultural power was recently introduced suggests that may indeed be the case (Mukherji et al. 2009; Meenakshi et al. 2012).

6. This assumes that the load of their pump is stable over time and proportional to HP, a fact that was verified with UGVCL data.

sumers receive the same duration of power supply, and anecdotal evidence suggested that most of them use it to the maximal possible capacity, especially during the drier parts of the year.

2. STUDY AREA AND PROGRAM IMPLEMENTATION

In April 2011, after a 2-year period of fieldwork and dialogue with the GoG and UGVCL, the program was piloted in a small study area by UGVCL and the CWC.

2.1. Study Area

The study area is located in northern Gujarat, one of the most groundwater-depleted parts of India (fig. 2), where water table declines have been a source of concern for decades (Moench 1992a, 1992b). Shah (2007) considers northern Gujarat to be one of the first areas in India to be entering into an anticipated phase of decline of groundwater irrigation as a result of overextraction.

Surveys we conducted in the study area show that water tables are as much as 300 meters deep, having declined at a rate of 3 meters per annum over the last 3 decades. Bore wells now reach as deep as 400 meters and require pumps of 60–70 HP to lift water. More than a staggering 50% of all power supplied by the regional utility, UGVCL, is used for pumping groundwater. Our field measurements showed usage of up to 10,000 units (KwH) per hectare of irrigated land annually, about five times the national average. These are, to be best of our knowledge, the first precise measurements of energy use in agriculture in India. At such depths and energy intensity, the value of the energy used for pumping water may become comparable to the net value of the crops that are irrigated with it (CWC 2011).

The study area offers several advantages as a pilot site for the program. First, a feeder separation program that separated power supply to agriculture and to other users was completed in 2006 and led to high quality power supply to agricultural consumers on dedicated feeders and to a curtailment of illegal usage (Shah et al. 2008). Second, the large capacity of the pumps meant that each pump tended to utilize an entire transformer (a node in the electricity grid) on its own. This has made it logistically easier for UGVCL to operate and read meters for participating consumers. Third, reliable power consumption data have been collected by UGVCL at the aggregate feeder level (a node in the grid serving 30–40 consumers) since the implementation of feeder separation, assisting the design and evaluation of the program (see below).

However, the extreme rates of depletion in the area raise questions of external validity of our findings to other regions in India where depletion is less advanced. On the one hand, deeper water tables mean that the marginal value of a unit of electricity is lower in this area, since more energy is required to draw the same amount of water from deeper depths. This suggests that response to the incentive program observed in this area (in terms of demand reduction, for example) might be lower in parts of

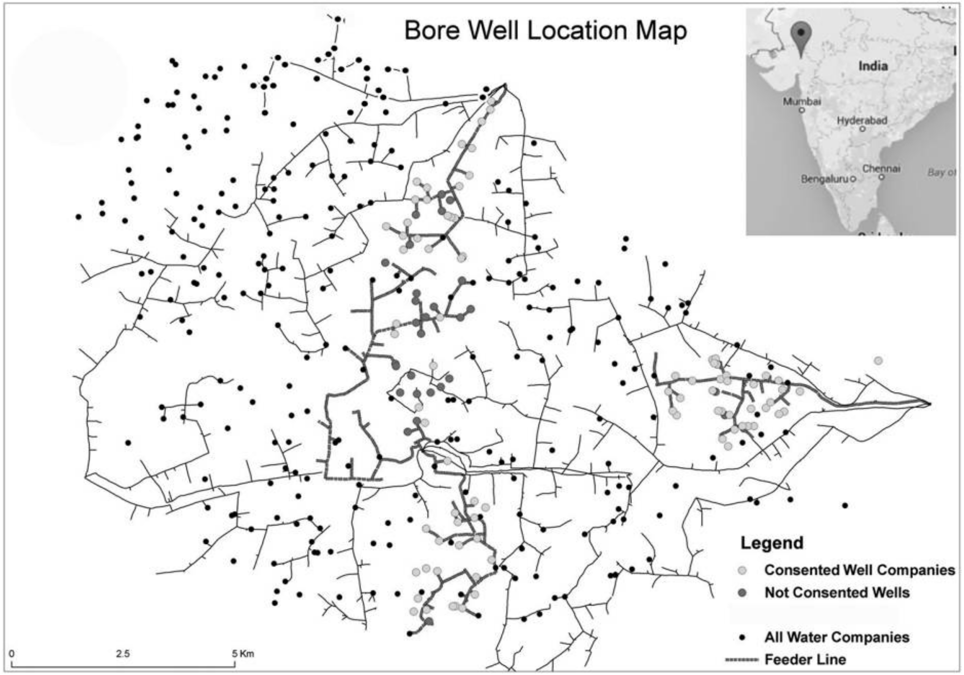

Figure 2. Grid lines and the location of consumers. Black lines indicate electric grid lines. Grid lines belonging to the four treated feeders are indicated in thicker gray lines. Dots indicate the location of wells (agricultural electricity connections) that are connected to the grid. Smaller black dots belong to control feeders and larger dots belong to treated feeders. Among the latter, light gray dots indicate consumers in the treatment feeders who have consented to participate in the program, and darker gray dots indicate those who had declined to participate. The location of the study area is indicated in the map on the top right corner.

the country that have shallower water tables. On the other hand, given that farmers are no longer able to irrigate their entire landholding, farmers are already facing strong incentives to increase the amount of water used per unit area, meaning that they have already harvested "low hanging fruit" in terms of efficiency.

Another issue affecting external validity has to do with collective well ownership. To finance the high costs of deep well drilling and powerful pumps, farmers in this area tend to congregate into informal water cooperatives, numbering an average of 10 shareholding farmers who operate the well collectively and share both access and maintenance costs (including electricity bills) through complex systems of internal accounting. Formally, however, each well is registered with UGVCL in the name of one of the shareholders, who is usually the one on whose land the well is situated and typically holds the largest share. Water cooperatives also sometimes sell water to other farmers, called *water buyers*, on the basis of need and availability (Dubash 2000).

Joint management of wells raises a concern that imperfectly cooperative groups may fail to distribute rebates for reduced usage accurately within the group and, as a result, that individual members will not be inclined to respond to the incentive, lowering the program's impact. For example, well owners who are formally registered with UGVCL may attempt to capture any rebates offered to that consumer, especially if individual usage may be hard to observe. And even if the distribution of rebates is transparent, if they are not distributed on the basis of each co-owner's own reductions in usage, this can result in free-riding and reduce individual co-owners' incentives to reduce their usage. While this is a very valid concern, we note that well co-owning groups implement rather sophisticated cost and water-sharing systems on a continuous basis. Individual usage by cooperative members is scheduled and often monitored by a dedicated well operator who is hired by the group to manage its operations. Members are charged internally, often on the basis of usage, a fee that is used to finance the running costs of electricity and well and pump maintenance. Any remaining unused funds are distributed among the members at the end of each year. These existing distribution systems and the strong within-group accountability would make it relatively easy to manage and distribute the rebates received by the group for reductions in aggregate usage, if the group chose to implement such a system. We believe it is unlikely that well owners could manipulate and capture such reductions in the well's electricity bill given the strong cost-sharing mechanisms that are in place, but we are unable to observe how and if rebates were distributed within the group.

One more concern has to do with the potential for collusion in which treated consumers shift some of their water usage to neighboring nontreated consumers in exchange for a portion of the associated rebates. In practice, we believe this to be an unlikely scenario in this area, for three reasons. First, transport costs of water are very high, at least in the short run, because water is usually delivered to end users through underground concrete channels that run from the well to the fields. The typical distances between different wells are large enough to make changes to the delivery systems costly and complicated. Local utility officials as well as local farmers who were consulted with about this possibility were confidant that the construction of new delivery channels in the short term was extremely unlikely. Second, CWC field staff who closely monitored the program's implementation in the field have not reported any such efforts. Third, we also note that most wells make maximal use of the power available to them outside of the rainy season (this power is rationed by the local utility and limited to 8 hours per day) so there would be little possibility of loading additional consumption to untreated wells, unless these wells increased their load, which is prohibited and closely monitored by the local utility. Nevertheless, from a broader perspective, program design should take into account the possibility of collusion and of other forms of slippage.

2.2. Program Implementation

Electrical consumers are organized into feeders, nodes of the electrical grid that typically serves 30–40 consumers. The pilot was implemented in four out of the 28 agricultural feeders belonging to the Kukarwada substation. These four treatment feeders, being representative of a variety of hydrological circumstances, were originally surveyed by CWC before the pilot was planned, and then selected by UGVCL for the pilot. UGVCL officials maintain that these feeders do not differ from other feeders in any significant technical or socioeconomic way.

The four treatment feeders serve 134 consumers (fig. 2), of which 113 were technically eligible to participate in the program.[7] All of these consumers were invited by UGVCL to join the pilot. Consumers served by the remaining 24 feeders serve as a control group (see below).

To determine baseline entitlements, UGVCL divided the year into six billing cycles[8] and then determined each period's baseline entitlement by multiplying every participating consumer's pump load with the estimated average number of hours of power usage in each period. This average duration of power usage was estimated on the basis of past consumption data, measured at the aggregate feeder level. The resulting daily duration of usage that was used to determine baseline entitlement is reported in table 3. It tends to be lower during the rainy season (June–September) and climbs up toward

7. Some UGVCL consumers, especially those who have relatively new connections, are metered and billed at a rate that is roughly equivalent in total expenditure to the flat rate tariff. They were not considered eligible for this pilot, which was focused on voluntary metering of existing consumers.

8. The six periods were meant to coincide with the bimonthly bill cycles, except that the first period was extended to last for 3 months because of administrative delays.

the maximum possible 8 hours/day (the rationed daily supply) at the height of the dry season.

Prior to the announcement of the program, UGVCL staff performed a verification of the load (capacity, in HP) of all consumers in the pilot area. Following load verification, during February–March 2011, UGVCL representatives visited all eligible consumers in the pilot area and invited them to participate in the pilot project. The terms of the offer were as follows:

1. Participating consumers will receive bimonthly entitlements of electricity usage amounting to the product of their (verified) contracted load and a certain number of hours for each billing period that was identical for all consumers and calculated as explained above.
2. Participating consumers agree that UGVCL will install and regularly (once a month) read a meter on their electrical connection.
3. UGVCL assures participating consumers that the metering will not be used for introducing unit-based billing but only for the purposes of rebating them for voluntary reductions of energy usage.
4. Participating consumers are free to withdraw from the program at any time. They may continue to pursue their present pattern of electricity usage and will not be penalized for usage that exceeds the determined baseline entitlement.
5. Should consumers raise their HP during the pilot period (subject to approval), their baseline will not change and it will remain frozen at the original level (in terms of electrical units).

Meters began to be read in April 2011, and consumers were informed through by mail of their compensation levels, even though, for technical reasons, the first rebates were only issued in October. During the entire process, CWC staff worked closely with UGVCL staff to administer the program. At the end of the first year of the pilot, CWC staff withdrew their support, and we believe the administration of the program was substantially slower after that point. Figure 3 summarizes the implementation time line.

3. RESULTS

3.1. Participation and Compliance

Of the 113 eligible consumers who were received an offer to participate, 84 consented (an acceptance rate of over 75%). Even though concerns and suspicions about future billing were common among consumers (and were the main reason for declining), most consumers seemed to be attracted by the possibility of obtaining the financial benefits. Thus, a pervasive notion in Indian policy circles, according to which suspicions of this kind would prevent the implementation of voluntary reforms in agricultural energy

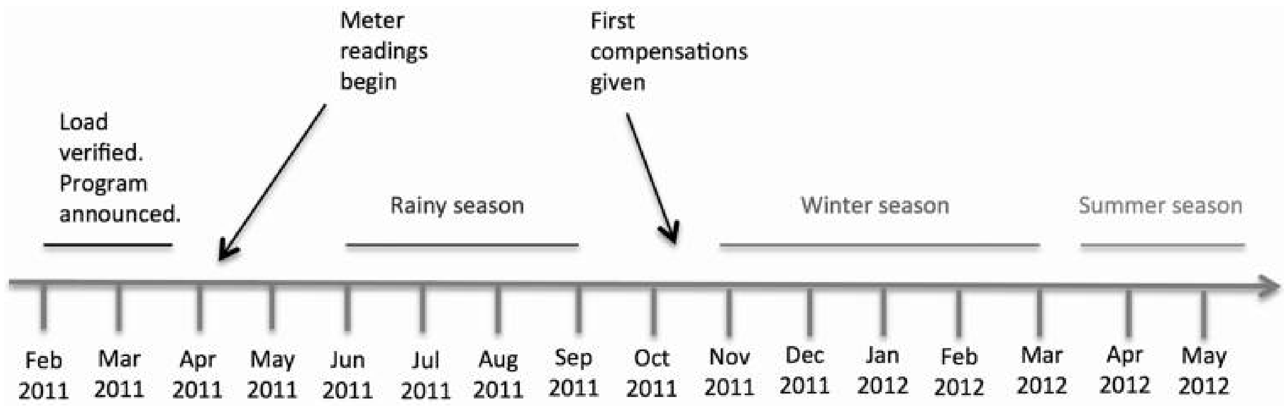

Figure 3. Implementation time line. The program started in April 2011 with a verification of the existing load of existing consumers. The first rebates were delivered to consumers in October, before the winter season begun. The analysis of this paper refers to the year between April 2011 and April 2012.

pricing, was found to be incorrect. However, we note that both UGVCL and CWC staff engaged in an intensive awareness campaign to alleviate consumers' concerns in order to achieve this result.

Figure 2 shows the locations of the wells of all consenting and nonconsenting consumers in the pilot area. As the figure indicates, most of the declining consumers belonged to one of the four treatment feeders (Bilodara feeder), and CWC staff reported that a few farmers fomented suspicions among their peers in that area. To explore other determinants of consent, we regressed the probability of consent on several consumer characteristics. The results are reported in table 2. Despite limitation of statistical power, they suggest that consumers with relative abundance of water (relative to their own needs), that is, those who are able to cultivate most of their land in the winter

Table 2. Regression Estimates for the Probability of Participation in the Program

	Probability of Participation		
	(1)	(2)	(3)
Depth to water (10 feet)	.01	.00	.00
	(.01)	(.00)	(.01)
Pump load (10 HP)	−.08**	−.02	−.04
	(.02)	(.03)	(.04)
Single owner	.19*	.08	.03
	(.09)	(.09)	(.10)
Sells water	.05	.20*	.20*
	(.09)	(.09)	(.09)
Fraction of land irrigated in winter	.41*	.25	.28
	(.19)	(.18)	(.19)
Fraction of land irrigated in summer	.01	−.01	−.02
	(.11)	(.10)	(.10)
Constant	.47	.38	.84
	(.36)	(.35)	(.53)
Village fixed effects	No	No	Yes
Feeder fixed effects	No	Yes	No
N	109	109	109

Note. Dependent variable: a binary indicator of whether consumers consented to participate in the pilot. Column 1 reports OLS estimates. Columns 2 and 3 control for feeder (4) and village (13) fixed effects, respectively. Standard errors in parentheses.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

season, the primary agricultural season, and those selling water were more likely to consent. There is weak evidence that single well owners were also more likely to consent.

On the other hand, as we report below, rebates were eventually offered to about 50% of consumers (see next subsection). Since baseline usage was determined based on aggregate average consumption data, this is what we would expect to see if there was no treatment effect, no self-targeting into the program by consumers whose usage falls below baseline levels and if the distribution of hours of usage is symmetric enough around the mean.

There were no indications of attempts to tamper with meters in the course of the pilot. In only three cases did UGVCL equipment indicate meter malfunction, and in all cases intentional tampering was deemed an unlikely cause by UGVCL. On the utility side, UGVCL has been able to take regular meter readings without interruption and calculate and issue six bills during the first year of the pilot. While CWC staff supported UGVCL throughout, this proves the feasibility of administering the scheme. A second pervasive belief in India policy discussions about the impossibility of transitioning back to metering and usage-based billing was thus also found to be incorrect.

3.2. Energy Usage and Rebates

Table 3 and figure 4 summarize the outcomes of the pilot in terms of aggregate electricity consumption over the six billing periods of the first year. Baseline consumption levels seem to have predicted actual aggregate consumption reasonably well outside of the monsoon season (July–October). The unusually abundant monsoon in 2011–12 is probably responsible for the lower than anticipated consumption levels in July–August, as a result of which all participating consumers received rebates. There was some increase in consumption immediately following the monsoon in September–October in comparison to baseline levels. In the summer of 2011 (April–June) and during the dry winter season of 2012 (December–March), when agriculture is critically dependent on irrigation, we find broad similarity between baseline and actual consumption, and rebates were given to about 50% of the consumers. This is suggestive of an absence of self-targeting by low electricity users into the program and of a lack of any treatment effect on electricity usage. In the next subsection, we turn to a formal estimation of the treatment effect.

As discussed above, the determination of baseline hours in a uniform way on the basis of aggregate consumption data inevitably leads to inaccuracies. Consumers whose usage exceeds the average will not be compensated for some of their savings, and those whose usage falls below the average will receive rebates that are unwarranted by any actual reductions in usage. Under the assumption that the incentive had no impact on actual consumption of electricity, these "unwarranted" rebates amounted to an annual level of about $300 per consumer. As mentioned above, we also found that the variability of the monsoon rainfall can have large impacts on energy consumption. Future implementations of similar programs may do well to either exclude the rainy

Table 3. Pilot Outcomes—Energy Usage and Rebates

		Billing Cycle and Time Period						
		1	2	3	4	5	6	
Unit		Apr–Jun	Jul–Aug	Sep–Oct	Nov–Dec	Jan–Feb	Mar	Annual
	Baseline hours per day	8	4.4	2.3	6.6	8	8	
Months	Duration	3	2	2	2	2	1	12
	Number of participating consumers	83	83	83	83	83	83	83
Horsepower	Total contracted load[a]	5,334	5,334	5,334	5,334	5,334	5,334	5,334
Horsepower	Total baseline load[a]	5,078	5,078	5,078	5,078	5,078	5,078	5,078
100,000 KWh	Total baseline consumption	27.3	10.2	5.3	15.2	18.2	9.1	85.2
100,000 KWh	Actual consumption	27.5	2.6	10.2	18.1	17.7	9.1	85.2
100,000 KWh	Aggregate difference baseline-consumption	–.2	7.6	–4.9	–2.9	.4	–.1	0
	Number of consumers eligible for rebate	35	83	3	12	48	41	
100,000 KWh	Total units rebatable by eligble consumers	1.6	7.6	.1	.2	1.5	.7	11.7
100,000 Rs	Value of baseline consumption at 2.5 Rs/unit	68.2	25.6	13.3	37.9	45.5	22.7	213.1
100,000 Rs	Total flat rate bill (all consumers)	10.8	7.2	7.2	7.2	7.2	3.6	43
100,000 Rs	Amount rebatable (without cap)[b]	4.1	19.1	.1	.5	3.7	1.7	29.3
100,000 Rs	Amount rebated (with cap)[b]	2.7	7.2	.1	.5	2.4	1	13.9
1,000$ /consumer	Value of baseline consumption at 2.5 Rs /unit	1.46	.55	.28	.81	.97	.49	4.56
1,000$ /consumer	Total flat rate bill (all consumers)	.23	.15	.15	.15	.15	.08	.92
1,000$ /consumer	Amount rebatable (without cap)[b]	.09	.41	0	.01	.08	.04	.63
1,000$ /consumer	Amount rebated (with cap)[b]	.06	.15	0	.01	.05	.02	.3

[a] Contracted load refers to the registered power of each consumer's pump. Baseline load refers to the pump capacity, as measured by UGVCL prior to the start of the experiment for the purpose of calculating baseline consumption. UGVCL did not want to change the contracted load of participating consumers but determined the baseline load as the minimum between contracted and measured load, which is why it turned out lower than contracted load.

[b] Amount rebatable refers to the difference between actual and baseline consumption for those consumers who consumed below baseline levels. The amount actually rebated may be lower because of the cap imposed by UGVCL's decision to compensate consumers by reducing their flat rate bills. Once that bill was reduced to nil, additional reductions in consumption below baseline were therefore not rebated.

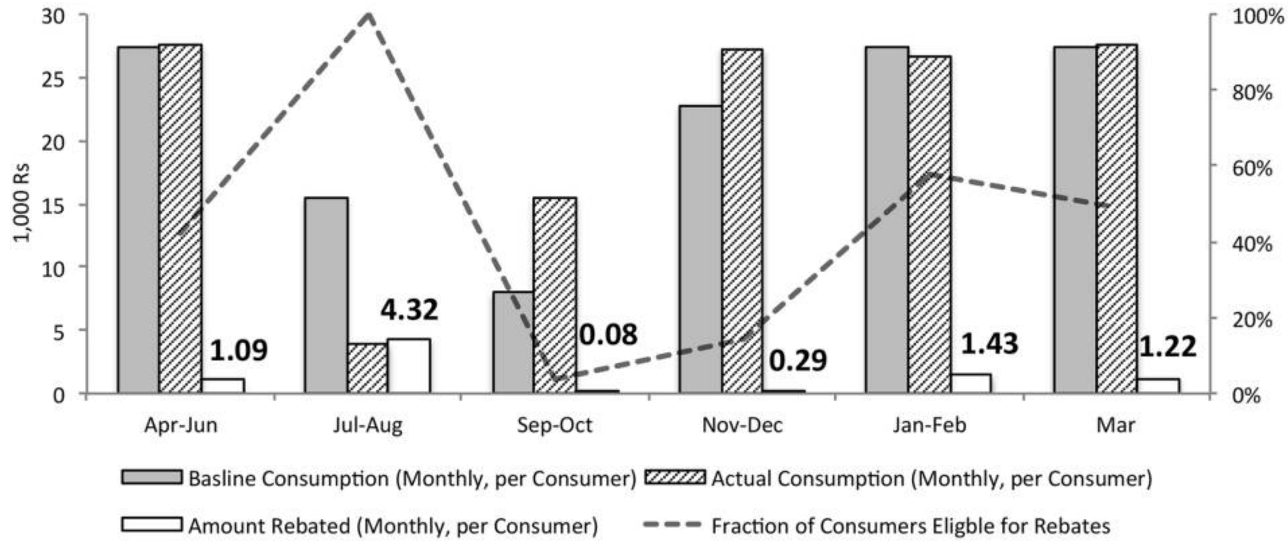

Figure 4. Program outcomes. The program was implemented in six billing cycles. Solid (*leftmost*) gray bars indicate the average baseline consumption benchmark, in units of 1,000 Rs. per month. Patterned (*middle*) bars indicate actual consumption observed in each billing cycle. Solid white bars (*rightmost*) indicate the amount actually rebated to consumers whose usage fell below the benchmark. The dotted line indicates the proportion of consumers who were eligible for these rebates.

season from the program, or to unify it into a single billing cycle with a lower baseline level of at most 2 hours per day. Doing this would have reduced the amount of unwarranted (inframarginal) transfers to $160 per consumer per year.

3.2.1. Empirical Strategy

Since metering electricity consumption is part of the treatment, a major challenge to estimating the impacts of the pilot was the absence of metering of nonparticipants. To overcome this challenge, we employed two different estimation strategies.

Feeder Level Analysis. Even though UGVCL does not normally meter individual consumers who pay flat rate bills, UGVCL does monitor electricity "sent out" to different feeders on a monthly, feeder-wise basis and these data are available to us for all 28 feeders (four treatment and 24 control) from April 2009, 2 years prior to the beginning of the pilot implementation, until April 2013, 2 years after the beginning of the pilot. Actual electricity consumption by consumers is lower than "sent out" electricity, mainly because of transmission and distribution losses, but these losses are not expected to differ much across feeders. Our primary empirical strategy is based on a difference-in-difference analysis of feeder-level power use data. We estimate a regression:

$$\log C_{f,y,m} = T_{f,y,m} + a_f + b_{y,m} + \varepsilon_{f,y,m}, \tag{1}$$

where $C_{f,y,m}$ is power consumption at feeder f at year y in month m; T is the treatment indicator (taking the value 1 for the four treatment feeders starting in April 2011, when the pilot began, and 0 otherwise); a_f are feeder fixed effects; and $b_{y,m}$ are fixed effects for each month- year combination in the sample that control, for example, for changing annual and monthly weather conditions and the crop cycle.

We chose a logarithmic model in C because one can decompose $C_{f,y,m} = L_f \times H_{f,y,m}$ where L represent load and H represent the total number of hours of electricity usage per month. The load of each feeder is hard to change, because of UGVCL regulations, so it can be safely assumed to be constant over the course of the study and, being time independent, can be absorbed by feeder fixed effects in the logarithmic model. Any changes in consumption over time, including any responses to the program should mostly occur along the H dimension. In the absence of treatment, one should therefore expect parallel changes in percentage terms, rather than in levels, making the logarithmic model more appropriate.

Individual Hours of Usage. Nontreated consumers were not inclined to have meters installed and read on their pumps, due to the prevailing suspicions of UGVCL's intentions. An innovative approach to overcoming this limitation involved the use of hour-meters, devices that keep track of cumulative hours of usage of the pump, rather than measuring electricity units. To form a control group, we randomly sampled 260 consumers in the 30 control feeders and surveyed them prior to the pilot. CWC then installed a total 100 hour-meters among randomly selected consumers in the treatment and control samples and read them on a monthly basis during the first year of the pilot.

Two of these devices malfunctioned during the pilot. Among the 98 functioning devices, 51 were in treated wells and 47 were in control wells. We refer to this sample as the HM1 sample. Of the 98 consumers who had functional hour-meters, 75 reside in villages that are served by the four treatment feeders (feeder lines are independent of village boundaries, so that consumers in the same villages are often served by different feeders and vice versa). We refer to this subsample as the HM2 sample.

The hour-meter readings provide us with individual level data on the duration of pump usage, which is equivalent to power consumption under the plausible assumption that pumps' load remained stable during the pilot. We use these data for an additional estimation of the pilot's impacts. However, evaluating the impact by the use of these data is potentially biased for two reasons: first, because the selection of the intent-to-treat (four feeders) group was not random; and second, because only treated (participating) consumers installed hour-meters in the intent-to-treat sample (the four treatment feeders). The resulting "treatment effect on the treated" is biased upward if we assume that consenting consumers were ex ante more likely to respond to the program by reducing usage, that is, it overestimates the extent of the response to the program through reductions in electricity usage.

3.2.2. Summary Statistics and Balance Tests

Table 4 reports summary statistics and tests of balance. The average consumer (in the entire sample, reported in col. 1) has a 570 feet deep well, equipped with a 60 HP pump. Twenty percent of the consumers are single owners, and the rest are informal cooperatives ("water companies") consisting, on average, of 13 shareholders. Forty percent of the consumers sell water to an average of about six water buyers (who do not own shares in the well). The average consumer well has about 50 bighas (about 12 hectares) of land in its command owned by the shareholders. Out of this potential, about 70% is irrigated in the winter season, and 40% in the hotter summer season, reflecting binding water scarcity in these areas. The values of these variables are very similar in the subsample of consumers for which hour-meters were installed (the HM sample, col. 2).

Columns 3–5 report estimated differences between the control and treatment groups' means for the above variables. Column 3 reports estimates that use the entire sample. Consumers in the treatment feeders have wells that are about 44 feet deeper, and those of them that are owned by cooperative water companies have about four additional shareholders. Other differences are not statistically significant. Our primary estimation strategy utilizes feeder level power consumption data in a difference-in-difference regression that controls for feeder fixed effects and, therefore, for all such differences between feeders.

Column 4 reports estimates that use a restricted subsample of consumers for which hour-meters were installed (our secondary estimation strategy utilizes consumer-level data from hour-meters from this sample). Column 5 further restricts the comparison to consumers residing in the same villages as the treated consumers. While none of the

Table 4. Balance Tests: Comparison of Consumer Attributes between the Treatment and Control Groups

			Diff: Control-Treatment		
	Sample: All (1)	Mean: HM (2)	All (3)	HM1 (4)	HM2 (5)
Depth to water (feet)	570.5	581.6	−43.68***	−31.76	−19.78
			(10.40)	(26.27)	(29.27)
Pump load (HP)	71.0	69.4	7.39	9.10	7.16
			(7.30)	(6.77)	(7.49)
Single owner	.2	.3	.00	−.03	−.05
			(.06)	(.09)	(.12)
Number of shareholders	13.0	11.3	4.14**	2.11	4.42
			(1.68)	(1.94)	(2.64)
Sells water	.4	.5	.09	.20	.13
			(.14)	(.15)	(.17)
Number of water buyers	6.3	6.4	.86	.72	.72
			(.74)	(1.18)	(1.45)
Land in command of well (bigha)	51.1	48.4	8.52	7.07	12.98
			(5.85)	(6.56)	(7.58)
Land irrigated in winter (bigha)	35.3	34.2	7.36	3.68	7.70
			(5.88)	(8.33)	(8.98)
Land irrigated in summer (bigha)	17.1	17.2	1.48	−.33	−.13
			(3.67)	(5.02)	(5.55)
N			387	98	75

Note. Columns 1 and 2 reports means in the entire sample (all consumers surveyed in the treatment and control feeders) and the HM sample (consumers for whom hour-meters were installed). Column 3 reports differences between the entire treatment and control groups. Column 4 reports differences between the control and treatment consumers for whom hour-meters were installed (the HM1 sample). Column 5 reports the same differences except that control consumers are limited to those residing in the same villages as treatment consumers (the HM2 sample). Standard errors, clustered at the feeder level, in parentheses.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

differences are statistically significant, we note differences of considerable magnitude in the depth of the wells, the power of the pump, the number of shareholders and the probability of selling water. We control for these variables in the regressions that follow.

3.2.3. *Estimated Impacts from Feeder-Level Data*

Our primary empirical strategy is based on a difference-in-difference estimation of feeder-level data. Figure 5 plots the average monthly consumption of electricity (in KwH) in the treatment and control feeders during the sample period (starting from

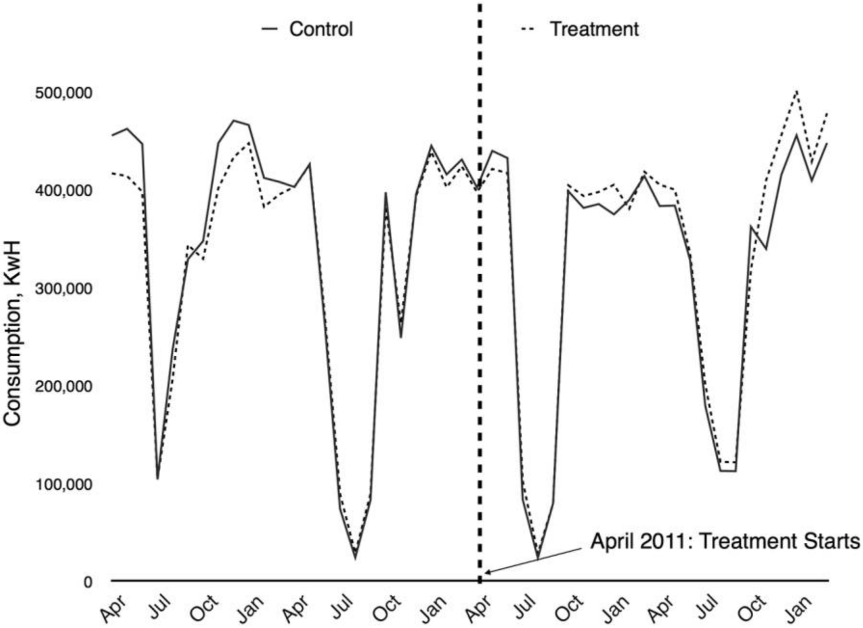

Figure 5. Control versus treatment feeders. Average monthly feeder consumption in KwH in the control (*solid line*) and treatment (*dotted line*) feeders from April 2009 to March 2013. The vertical line indicates the start of the treatment period.

April 2009, 2 years prior to the start of the program, and ending in April 2013). The seasonal oscillation of electricity consumption is clearly visible in the plot, with consumption dropping substantially during the rainy season (approximately June–September) in which irrigation is used much less. The plot is also highly suggestive of parallel pretreatment trends between control and treatment feeders and an absence of any treatment effects.

A formal event study is also displayed in figure 6. To derive this plot, we estimated a regression

$$\log C_{f,y,m} = \sum_{y,m} \kappa_{y,m} I_{y,m} \times T_f + a_f + b_{y,m} + \epsilon_{f,y,m}, \tag{2}$$

where $I_{y,m}$ is a dummy indicator for the time period corresponding to year y and month m, T_f is a feeder-level indicator of whether the feeder was treated or not, a_f are feeder fixed effects and $b_{y,m}$ are year-month fixed effects. We then plotted the point estimates and confidence intervals of $\kappa_{y,m}$ over time. The point estimates are imprecise, but none are significantly different from zero and they do not display a trend or a break after treatment begins.

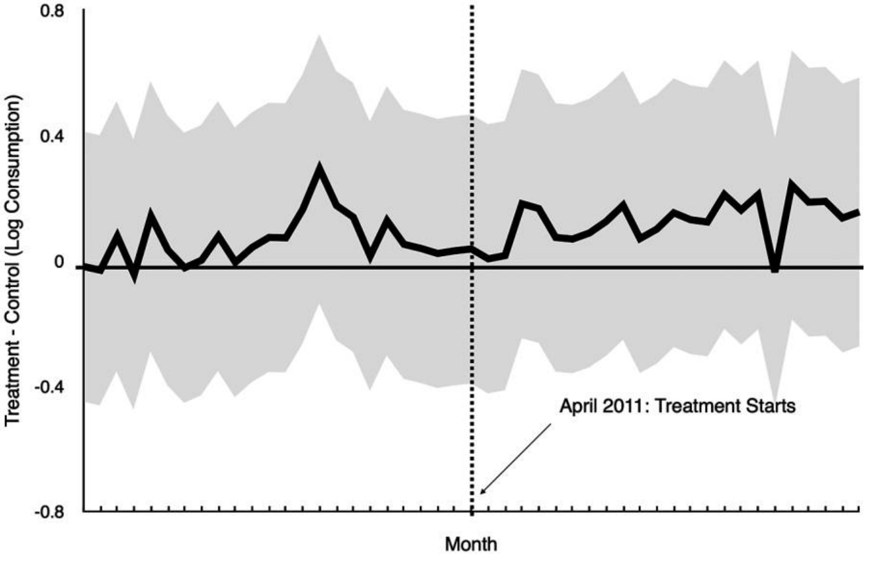

Figure 6. Control versus treatment feeders. A plot of coefficients from regression (2) which estimate the difference between (Log) average consumption in the treatment and control feeders in each month of the sample period. Shaded areas represent 95% confidence intervals. The dotted line indicates the start of the treatment period.

Formal difference-in-difference estimates of the program's impacts are reported in table 5. The first year of the pilot concluded in April 2012, and CWC then withdrew its support for the administration of the program because of a loss of interest by the government to expand the program. Even though the pilot was planned to last for 3 years, the implementation in the following year may therefore not have proceeded in the same manner. We therefore estimate regressions that include (cols. 1, 3) and do not include (cols. 2, 4) the second year in the sample. We also estimate two variants of the model, one that controls for month and year fixed effects (cols. 1 and 2) and one that controls for interacted month-year fixed effects (cols. 3 and 4). For each model, we report 95% confidence intervals calculated in two ways. The first uses ordinary least squares (OLS). The second clusters errors at the feeder level in order to deal with biases potentially resulting from serial correlation in errors, as suggested by Bertrand et al. (2004). Finally, in column 5, we follow an alternative procedure suggested by Bertrand et al. (2004) in which the sample is collapsed by time into two time periods consisting of pre- and posttreatment (consumption is first regressed on month and year indicators and residuals are then collapsed). This procedure leaves us with a smaller sample of 54 observations.

Reductions in electricity usage in response to the incentive program would be reflected by negative treatment coefficients. As table 5 shows, all point estimates are small

Table 5. Treatment Effects on Aggregate Feeder Power Consumption

	Year 1 (1)	Years 1+2 (2)	Year 1 (3)	Years 1+2 (4)	Year 1 (5)
	Treatment				
	.02	.06	.03	.06	.02
	[−.14,.18]	[−.07,.19]	[−.07,.13]	[−.02,.15]	[−.31,.35]
	[−.13,.18]	[−.12,.24]	[−.13,.18]	[−.12,.24]	
Feeder FE	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	
Month FE	Yes	Yes	Yes	Yes	
Year × Month FE	No	No	Yes	Yes	
N	927	1251	927	1251	54

Note. Dependent variable: the logarithm of monthly consumption. The sample consists of monthly observations during 2009–13 for 28 feeders, of which four feeders consist of the treatment group. Columns 1 and 3 include year 2 of the pilot in the sample, and columns 2 and 4 omit it. 95% confidence intervals (CI) are reported in brackets. The top CI estimates are based on OLS standard errors. The bottom CI estimates are based on clustering at the feeder level. Column 5 reports estimates from a sample in which observations were collapsed over time into two "periods" consisting of pre- and posttreatment (see text for details). FE = fixed effects.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

(and positive) and statistically insignificant. In our preferred specification (cols. 3 and 4), when standard errors are estimated by OLS, we are able to reject a treatment effect greater than about a 7% reduction in electricity usage (i.e., a coefficient that is lower than −0.07), about a third of the upper 20% cap on savings imposed by UGVCL. When errors are clustered by feeder, we can reject an effect greater than a 13% reduction in consumption, an effect still lower than the anticipated impact. When we collapse the sample over time, the sample becomes very small, and confidence intervals become quite large, enabling us to only reject an effect greater than a 31% reduction in usage. We believe that the sum of the evidence is highly suggestive of a lack of any substantial treatment effects.

3.2.4. Estimated Impacts from Hour-Meter Data

Table 6 reports results from regressions of data measured by hour-meters (average daily hours of usage between December and June of the first year of the pilot) on a treatment indicator. Hour-meter readings were not available prior to November. We report usage starting in December because by that time we are confident that consumers were well aware and confident of the incentive program, having received rebates for the rainy season in November. The regression is limited to the subsample of consumers for whom

Table 6. Treatment Effects on Daily Hours Use

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
	Panel 1. All HM Users (HM1 Sample)						
Treatment	.38	.12	.07		.20	.29	.37
	[−.05,.82]	[−.25,.48]	[−.31,.45]		[−.35,.75]	[−.32,.89]	[−1.22,1.96]
Daily hours used, November		.59***	.57***		.57***	.57***	.58***
		[.35,.83]	[.30,.84]		[.31,.82]	[.32,.81]	[.30,.86]
Treatment × Single owner					−.44		
					[−1.18,.31]		
Treatment × Sells water						−.44	
						[−1.36,.47]	
Treatment × Share irrigated land							−.42
							[−2.43,1.59]
Observations	98	89	88		88	88	88
	Panel 2. HM Users in Same Villages (HM2 Sample)						
Treatment	.45	.16	.09	.18	.17	.29	.86
	[−.09,.99]	[−.41,.73]	[−.50,.68]	[−.43,.80]	[−.61,.96]	[−.64,1.22]	[−1.48,3.20]
Daily hours used, November		.54**	.50**		.50**	.50**	.51**
		[.20,.87]	[.14,.86]		[.15,.86]	[.16,.84]	[.15,.87]
Treatment × Single owner					−.29		
					[−1.27,.69]		
Treatment × Sells water						−.44	
						[−1.63,.75]	
Treatment × Share irrigated land							−1.07
							[−3.95,1.82]
Observations	75	66	65	75	65	65	65
Pretreatment daily hours	N	Y	Y	N	Y	Y	Y
Other controls	N	N	Y	N	Y	Y	Y
Village fixed effects	N	N	N	Y	N	N	N

Note. Dependent variable: Mean daily hours of power use, December–June 2011, as measured by hour-meters. Panel I reports estimates of regressions that use the entire sample of hour-meters users. Panel 2 reports estimates of parallel regressions that use only the sample of hour-meters users that reside in the same villages as the treatment group. Col. 1 reports estimates of the basic model. Col. 2 controls for the average daily hours of usage in November (before treatment started). Col. 3 adds controls for whether the well is single owned, whether it sells water, and for the share of land that is irrigated in the dry season (estimates not reported). Col. 4 includes village fixed effects (panel 2 only). Cols. 5–7 include interactions between treatment and these three characteristics. Standard errors are clustered within feeders. 95% confidence intervals in square brackets.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

hour-meters were installed. As noted above, hour-meters were only installed for participating consumers among the treatment group, so the regressions estimate the effect of treatment on the treated. If participation in the pilot was more likely for consumers who were ex ante more prone to respond to the incentive program, the results overestimate the actual program effect. Nevertheless, we also estimate Lee bounds (Lee 2009) below.

We estimate regressions that use either the entire sample of hour-meter users (top panel), or a subsample that only includes those control consumers who reside in the same villages as the treated consumers (bottom panel). In each sample, we estimate several models. Column 1 reports estimates of the simplest model. Column 2 adds controls for the average daily hours of usage in November. This model is motivated by the possibility that November usage is likely to be little affected by the program, given that it was only then that rebates were starting to be made, and could therefore provide us with a measure of pretreatment usage. Column 3 adds controls for whether the well is single-owned, whether it sells water, and for the share of land that is irrigated in the Rabi season (estimates of these control variables are all insignificant and are not reported). Column 4 includes village fixed effects (bottom panel only). Standard errors are clustered within feeders.

Reductions in hours of electricity usage in response to the incentive would be reflected by a negative treatment effect. Point estimates of the treatment effect, reported in table 6, are all statistically insignificant and are of small, positive magnitude. The table also reports 95% confidence intervals. In all models, we are able to reject a treatment effect greater than 0.5 hours. This is about half the upper cap on savings imposed by UGVCL.

As noted above, even though we believe selection into the program is likely to result in underestimates of the treatment effect, we also calculate Lee bounds (Lee 2009) of the possible range of the intent-to-treat effect, and find effects ranging from −0.42 to 1.14. The 95% confidence interval of this range of effects (Imbens and Manski 2004; Lee 2009) is between −1.04 and 1.43. This lower bound is lower, naturally, than the lower limit of the 95% CI of our unadjusted point estimate but still provides a useful lower bound on the impact of the program.

To test for the possibility of heterogeneous effects, we report, in columns 5–7, estimates of interactions between treatment and three characteristics that could be hypothesized to be affecting response to the program: consumers who are single owners are hypothesized to have more flexibility to respond to the incentive for various reasons, including the possibility of adjusting irrigation schedules and easily distributing savings among the well co-owners; consumers who sell water to other farmers (other than the well co-owners) may be more likely to respond to the incentives by reducing sales; consumers who irrigate a greater fraction of their land during the dry season may be more likely to have "excess" water. All point estimates of these interactions are negative, consistent with the hypothesis of a stronger "response" to the incentive. However, limitations of statistical power render our estimates to be quite imprecise and statistically insignificant.

3.3. Self-Reported Water Saving

In addition to actual usage measurements, CWC also surveyed consumers in the treatment and control groups about their efforts to reduce energy and water usage. The results provide an illustration of the pitfalls of relying on self-reported behavior in evaluating an incentive program. Respondents were asked to indicate whether they made any effort to reduce water and energy usage, and if yes, how. The responses to the second question were then separated into two categories: a specific method or technology of irrigation, or a broad indication of a reduction in the duration of electricity usage. The former response indicates an observable and verifiable effort to save water, whereas the latter is much harder to observe externally.

Table 7 reports regressions of these responses on a treatment indicator among the hour-meter sample. The first row reports regression estimates of the probability (OLS) of indicating effort to save water. In the second row, the dependent variable is the probability of indicating effort through a specific and observable irrigation technology. In the third row, the dependent variable is the probability of indicating effort through a general reduction in hours of usage in some unspecified way. Column 1 uses the entire HM1 sample, column 2 limits the sample to those consumers residing in the same villages as the treated consumers (the HM2 sample), and column 3 reports estimates that include village fixed effects.

Table 7. Treatment Effects on Self-Reported Effort to Save Energy and Water

	(1)	(2)	(3)	(4)
Saving water	.20	.17**	.19**	.33***
		(.07)	(.08)	(.08)
Efficient irrigation	.11	.01	.03	.06
		(.05)	(.06)	(.07)
Reducing hours of use	.11	.22***	.22***	.20***
		(.01)	(.01)	(.06)
N		97	75	75

Note. Each row reports regressions of a binary indicator of self-reported saving effort on treatment status. First row: general indication of an attempt to save water. Second row: indication of saving water through some specific observable irrigation practice. Third row: indication of saving water through some general unspecified way of reducing the hours of usage. The sample consists of consumers who had hour-meters installed (HM1 sample). Column 1 reports the sample mean. Column 2 uses the entire HM1 sample. Column 3 limits the sample to consumers residing in the same villages as treated consumers (the HM2 sample). Column 4 reports estimates that include village fixed effects. Standard errors, clustered within feeders, in parentheses.

* $p < .05$.

** $p < .01$.

*** $p < .001$.

The results show that treated consumers were more likely, in a statistically significant manner, to report making an effort to save water (top row), indicating either strategic responses or genuine but failed efforts. As shown in the middle and bottom rows, this result is entirely driven by declarations of saving water in some unspecified and hard to verify manner, through a general reduction in the hours of usage. There was no effect on the probability of indicating a use of a specific irrigation technology (bottom row), which would be more easily observable and verifiable in the field by CWC or UGVCL staff.

As explained above, almost all consumers in the treatment area received compensation from UGVCL during the rainy season, despite having made no observed effort to reduce usage: the "savings" were a result of abundant rains that reduced the need for irrigation. Consumers were therefore aware of the program's benefits and openly expressed their satisfaction with it. Treated consumers may therefore have suspected that failing to report efforts to save water to CWC staff could lead to a withdrawal of the rebates or of the program itself and may therefore be strategically reporting saving effort. The fact that consumers only reported increases in unobservable ways of trying to save water, rather than through observable and verifiable specific practices is consistent with this interpretation of the results. A reliance on self-reported effort would have led us to erroneously conclude that the program had a substantial impact on water and energy usage.

4. DISCUSSION

The preceding sections describe consistent evidence for the lack of consumer response to the incentive program. Why have consumers not responded, and what lessons can we learn from this lack of response?

The conventional wisdom in discussions of the Indian groundwater crisis is that flat rate agricultural energy pricing is responsible for inefficient use of water and that marginal pricing would lead to substantial reductions in demand. As far as we are aware, our study provides some of the first, if indirect, empirical tests of this claim. To what extent do our results point against it? Do they suggest that voluntary approaches are unlikely to be effective?

To fix ideas, let b be the (unobserved) marginal loss associated with reductions in energy use for pumping, and let p be a marginal price on energy use to which consumers are exposed. The conventional notion is that b is smaller than any "reasonable" level of p, and as a result, that universal compulsory pricing of agricultural energy would lead to reductions in usage.

One way to interpret our results is that in fact, b is substantially higher than is usually thought. If true, this would suggest that even full pricing at the rate b would fail to reduce demand for power. However, it is important to acknowledge that there are a number of alternative explanations of our results that we are unable to rule out. Some of these have to do with the design and voluntary nature of the program we tested and the ways in which it differs from actual pricing, some have to do with specific features of the design of the pilot, and yet others have to do with unique features of the study area. We begin by discussing these alternative explanations.

One possibility we can rule out is that consumers did not understand or trust the mechanism. As described above, the monsoon rainfall that occurred early on during the pilot was unusually abundant and led to reductions in pumping for the simple reason that irrigation water was unneeded. Almost all treated consumers received rebates (in the form of substantially discounted bills) from UGVCL by November, which ensured their awareness of and confidence in the program. This was also reflected in their communications with UGVCL field staff.

It is much harder to rule out that the design of the program itself may have distorted consumer response. The mechanism differs from compulsory pricing in several important dimensions. As we have noted, baseline entitlements are likely to be inaccurate, leading to unwarranted transfers. In addition, behavioral factors may render the marginal utility loss from reductions in water use to be unequal to the marginal gains from increases in water use. Moreover, even though we find no strong evidence for it, the design of the program could have resulted in self-selection that may drive the results (note, however, that selection by those more prone to benefit should bias the results upward). In particular, the scope for "effortless" financial rewards with no accompanying behavior change may have discouraged participating consumers from reducing usage even though full pricing may have led them to do so.

There are also several circumstances that are specific to the study area which may have played a role in inhibiting consumers' response and which influence the external validity of our results. As mentioned above, the study area is located in a severely groundwater-depleted part of India. Water tables reach extraordinary depths of up to 1,000 feet. Since more energy is required to draw a unit of water from deeper depths, the marginal benefit of energy for agriculture is therefore lower in such an area in comparison to a similar area with a shallower water table. From this perspective, the study area should exhibit a stronger response to an incentive set at a fixed rate per unit of energy than other parts of India with shallower water tables.

The prevalence of cooperatively owned wells in the area, itself a likely result of deep water tables and the high costs of drilling wells, may also constrain individual well co-owners' ability to change their water usage patterns. First, as discussed in the section on program design, the cooperative structure of wells may make it hard for individual shareholders to receive rebates for individual water usage reductions. We did not observe the extent to which rebates were shared among the group members and so cannot rule out capture by the formal owner of the well. However, the cooperatives maintain sophisticated joint accounts and routinely distribute costs and profits among their members, which leads us to consider this possibility to be unlikely. On the other hand, shareholders distribute irrigation water from their well through a sophisticated but rigid scheduling of irrigations (Dubash 2000) that well co-owners often claim makes it difficult for any one co-owner to modify his or her irrigation practices in an attempt to reduce usage. On the basis of discussions with local farmers, we believe that this technical issue may have played a more powerful role in inhibiting response by cooperative consumers. Unfortunately, power limitations prevent us from addressing the question empirically. In the results reported above, we found a negative, but small and insignificant estimate of an interaction between treatment and single well ownership.

While we are unable to rule any of these alternative explanations out and to conclude that $b > p$, we believe it is worth considering this possibility given the paucity of empirical evidence on the matter and its great importance for policy.[9] Note that p, the rate of compensation, was set at a lower level than that advocated by CWC, below the marginal costs of supply to the utility and much below the domestic and industrial power tariffs. And yet, it would seem that at the rate of 2.5 Rs. per unit, p should be high enough to trigger a response, for two reasons.

It is often assumed that there are numerous low-cost ways to increase water use efficiency over the predominant open channel flooding, with little effect on agricultural productivity. However, during the course of the study it had become clear that while on paper such technologies exist, in practice, it is hard to come by solutions that are practically suited to local farmers' cultivation systems and would enable consumers to respond to the incentive. In the course of the pilot, farmers would often complain to CWC staff that they would like to benefit from the pilot by saving water but are unfamiliar with the required technologies and practices and would require instruction and training to do so. High-cost technologies, like drip and sprinkler irrigation systems, are well known water-saving technologies, and while they are rapidly diffusing in Gujarat in recent years (Fishman and Li 2014), they require heavy up-front investments (even with government subsidies) for which the incentives offered in the pilot are probably insufficient in the short term. At least in our study area, the government extension system does not seem to be familiarizing farmers with attractive low-cost water-saving practices. One possible lesson from this study is the need to emphasize the extension of such technologies, independently or alongside a pricing instrument, as part of a policy to address the groundwater-energy crisis.

The other reason that it may seem surprising that p was not high enough to generate a response is that its level exceeded the water rate in local informal water markets, in which farmers who do not own their own wells purchase water from well cooperatives. The distribution of these rates, on a per unit electricity basis, as reported in our surveys, is displayed in figure 7. Most well owners sell water at rates that are lower than the

9. Unfortunately, we do not have experimental evidence on the marginal benefit of electricity in agriculture. Kumar (2005) uses observational data to estimate rather low marginal benefits and concludes that marginal pricing should have substantial impacts on usage.

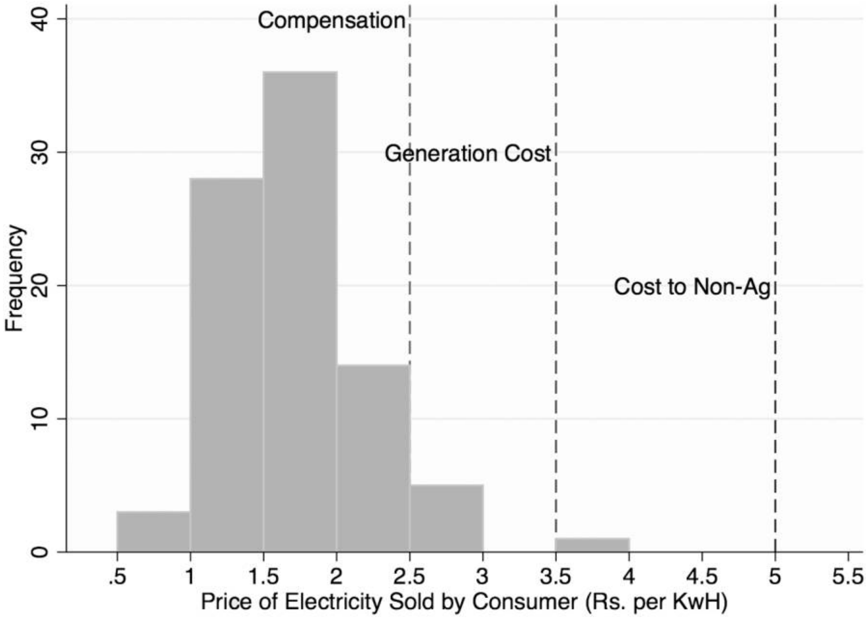

Figure 7. Histogram of water selling rates (Rs. per KwH) in local informal water markets. Dotted reference lines mark the cost of supply of electricity, the rate of compensation, and the rate at which electricity is sold to nonagricultural consumers.

2.5 Rs./KwH offered by UGVCL in the program. The incentive program therefore seems to at least present an opportunity for water-selling consumers to profit by reducing sales to water buyers and winning rebates from UGVCL instead. Indeed, this is a concern raised by Mukherji et al. (2009) on the potentially negative welfare impact that electricity pricing can have on water buying farmers in West Bengal. Why then did farmers not seem to utilize this opportunity?

We believe, on the basis of discussions with farmers' focus groups, that the answer may have to do with social norms that govern local water markets. Water rates in these markets do not seem to be determined by supply and demand for water, but by a social contract that determines the "fair" price of water. In fact, the rate at which water is sold is usually equal to the internal rate at which informal water cooperatives sometime charge their own members as a means to recover their collective expenses (power bill and maintenance costs). This sort of a social contract is also observed by Banerji, Meenakshi, and Khanna (2012) in another part of India. Many well owners also reported a social obligation to provide their neighboring water buyers with an adequate supply of water in order to maintain a long-standing relationship. Disturbing these social ties for what farmers may have perceived as a potentially short-term incentive program may have seemed unattractive, and results might have been different if farmers were certain of a long-term time line. In other words, well owners are constrained from altering the price or the quantity of water sales, and we believe these norms to play at least a part in explaining the observed behavior.

5. CONCLUSION

Increasing water scarcity will require substantial improvements in the efficiency of the allocation and use of water, particularly in agriculture. A commonly held view is that the introduction of accurate volumetric pricing of water, or of the energy required to pump it, will realign incentives and result in improved efficiency. However, political constraints commonly inhibit the implementation of price-based policies in water sectors.

The Indian groundwater-electricity crisis offers a striking example of this tension on a scale and urgency that are probably unparalleled elsewhere. The Indian Electricity Act of 2003 mandates the metering of all consumers in India, but political capacity to implement the act, let alone to achieve accurate billing of electricity in the agricultural sector, is lacking in most Indian states.[10] In lieu of metering and volumetric billing, policy makers in India have few policy tools with which to address the groundwater-energy crisis. Most utilities and state governments resort to the rationing of power supply in agriculture in order to control their budgets, but this approach has failed to effectively control subsidy expenditures or water withdrawals in the face of political pressure or to create accountability and transparency in the electricity sector.

The pilot implemented by CWC, the GoG, and UGVCL in 2011–12 offers scarce field evidence on the potential of alternative, voluntary approaches to address the Indian groundwater and energy crisis. A program of the kind evaluated in this study will suffer from inherent weaknesses—inaccurate baselines and self-targeting—that can carry social costs. Whether these costs exceed the potential benefits that may result from resulting reductions in energy and water use is a matter for empirical investigation. The results of this study indicate otherwise. Not only did the costs turn out to be substantial, but there was no evidence of any offsetting impacts on energy usage. However, we believe that the high take-up we observed, which is not to be taken for granted in the Indian context, calls for additional, more ambitiously designed experiments of similar programs in a variety of locations in India with diverse hydrological and agricultural circumstances. The pilot discussed here, while a first of its kind, was limited in several important ways. Future experiments should achieve better causal inference by using randomized control trials and larger samples, and they should vary the rate of compensation to be at least as high as the cost of electricity supply and preferably higher. We believe the results of the single pilot discussed here to be insufficient to deem this approach ineffective. Nevertheless, they point to two potential important lessons on the limitations of price instruments to improve the efficiency of agricultural water usage.

---

10. West Bengal is the primary exception, but it is not groundwater scarce and water tables are shallow (Mukherji et al. 2009)

First, social norms often play a large role in determining water prices and allocations. Second, without access to affordable technologies and to the relevant extension and training, farmers may not be able to respond to pure incentives in the way policy makers envision.

REFERENCES

Aeschbach-Hertig, Werner, and Tom Gleeson. 2012. Regional strategies for the accelerating global problem of groundwater depletion. *Nature Geoscience* 5:853–61.

Alix-Garcia, Jennifer M., Elizabeth N. Shapiro, and Katharine R. E. Sims. 2012. Forest conservation and slippage: Evidence from Mexico's national payments for ecosystem services program. *Land Economics* 88:613–38.

Bacon, R. W., and John Besant-Jones. 2001. Global electric power reform, privatization, and liberalization of the electric power industry in developing countries 1. *Annual Review of Energy and the Environment* 26:331–59.

Badiani, Reena, and Katrina Jessoe. 2013. The impact of electricity subsidies on groundwater extraction and agricultural production. Technical report, Working Paper, University of California at Davis.

Badiani, Reena, Katrina K. Jessoe, and Suzanne Plant. 2012. Development and the environment: The implications of agricultural electricity subsidies in India. *Journal of Environment and Development* 21:244–62.

Banerji, Abhijit, J. V. Meenakshi, and Gauri Khanna. 2012. Social contracts, markets and efficiency: Groundwater irrigation in north India. *Journal of Development Economics* 98:228–37.

Bertrand, Marianne, Esther Duflo, Sendhil Mullainathan, et al. 2004. How much should we trust differences-in-differences estimates? *Quarterly Journal of Economics* 119:249–75.

Boomhower, Judson, and Lucas W. Davis. 2014. A credible approach for measuring inframarginal participation in energy efficiency programs. *Journal of Public Economics* 113:67–79.

CWC (Columbia Water Center). 2011. Addressing the water crisis in Gujarat, India. Columbia Water Center White Paper.

Dinesh Kumar, M., and O. P. Singh. 2001. Market instruments for demand management in the face of scarcity and overuse of water in Gujarat, western India. *Water Policy* 3:387–403.

Dubash, Navroz K. 2000. Ecologically and socially embedded exchange: "Gujarat model" of water markets. *Economic and Political Weekly*, 1376–85.

———. 2007. The electricity-groundwater conundrum: Case for a political solution to a political problem. *Economic and Political Weekly*, 45–55.

Dubash, Navroz K., and Sudhir Chella Rajan. 2001. The politics of power sector reform in India. World Resources Institute. Washington, DC.

———. 2002. Electricity reform under political constraints. *Power Politics* 1:51.

Famiglietti, J. S. 2014. The global groundwater crisis. *Nature Climate Change* 4:945–48.

Fishman, R. 2011. Falling water tables in India—a review of the evidence. Photocopy.

Fishman, Ram, and Shan Li. 2014. Social learning and the diffusion of minor irrigation systems in India. Technical report, Working paper, Institute for International Economic Policy, Elliot School of International Affairs, George Washington University.

Gulati, Mohinder. 2011. How free or subsidised power to agriculture can be delivered. *Economic Times*, April 2. http://economictimes.indiatimes.com/articleshow/7848756.cms?utm_source=contentofinterest&utm_medium=text&utm_campaign=cppst.

IEA. 1999. *Looking at energy subsidies: Getting the prices right*. World Energy Outlook, 1999. Paris: International Energy Agency.

Imbens, Guido W., and Charles F. Manski. 2004. Confidence intervals for partially identified parameters. *Econometrica* 72:1845–57.

Ito, Koichiro. 2013. Asymmetric incentives in subsidies: Evidence from a large-scale electricity rebate program. Technical report, National Bureau of Economic Research, Cambridge, MA.

Jack, B. Kelsey, Carolyn Kousky, and Katharine R. E. Sims. 2008. Designing payments for ecosystem services: Lessons from previous experience with incentive-based mechanisms. *Proceedings of the National Academy of Sciences* 105:9465–70.

Johansson, Robert C., Yacov Tsur, Terry L. Roe, Rachid Doukkali, and Ariel Dinar. 2002. Pricing irrigation water: A review of theory and practice. *Water Policy* 4:173–99.

Krishna, Srivatsa. 2012. Why India needs freedom from free power. *Economic Times*, September 30.

Kumar, M. Dinesh. 2005. Impact of electricity prices and volumetric water allocation on energy and groundwater demand management: Analysis from western India. *Energy Policy* 33:39–51.

Lee, David S. 2009. Training, wages, and sample selection: Estimating sharp bounds on treatment effects. *Review of Economic Studies* 76:1071–1102.

Livingston, Morna. 2009. Deep wells and prudence: Towards pragmatic action for addressing groundwater overexploitation in India. Report. World Bank, Washington, DC.

Meenakshi, J. V., Abhijit Banerji, Aditi Mukherji, and Anubhab Gupta. 2012. Does marginal cost pricing of electricity affect groundwater pumping behaviour of farmers? Project report submitted to International Initiative for Impact Evaluation (3ie) by International Water Management Institute (IWMI), New Delhi.

Ministry of Water Resources. 2001. Results of the 3rd minor irrigation census. Technical report. http://mowr.gov.in/micensus/mi3census/preface.htm.

Moench, Marcus H. 1992a, Chasing the watertable: Equity and sustainability in groundwater management. *Economic and Political Weekly*, A171–A177.

———. 1992b. Drawing down the buffer: Science and politics of ground water management in India. *Economic and Political Weekly*, A7–A14.

Morgan, Trevor. 2008. *Reforming energy subsidies: Opportunities to contribute to the climate change agenda*. United Nations Environment Programme, Division of Technology, Industry, and Economics, Nairobi.

Morris, Sebastian. 2001. Power sector reforms and regulation: The road ahead." India Infrastructure Report. In *Issues in regulation and market structure*, chap. 6.2. New Delhi: Oxford University Press.

Mukherji, Aditi. 2007. The energy-irrigation nexus and its impact on groundwater markets in eastern Indo-Gangetic basin: Evidence from West Bengal, India. *Energy Policy* 35:6413–30.

Mukherji, A., B. Das, N. Majumdar, N. C. Nayak, R. R. Sethi, and B. R. Sharma. 2009. Metering of agricultural power supply in West Bengal, India: Who gains and who loses? *Energy Policy* 37:5530–39.

Mukherji, Aditi, and Tushaar Shah. 2005. Groundwater socio-ecology and governance: A review of institutions and policies in selected countries. *Hydrogeology Journal* 13:328–45.

Pfaff, Alexander, Juan Andres Robalino, and G. Arturo Sanchez-Azofeifa. 2008. Payments for environmental services: Empirical analysis for Costa Rica. Terry Sanford Institute of Public Policy, Duke University, Durham, NC, USA.

Planning Commission. 2012. Annual report (2011–12) on the working of state power utilities and electricity departments. Technical report, Power and Energy Division, Planning Commission, Government of India.

Reddy, Amulya K. N., and Gladys D. Sumithra. 1997. Karnataka's power sector: Some revelations. *Economic and Political Weekly*, 585–600.

Rodell, Matthew, Isabella Velicogna, and James S. Famiglietti. 2009. Satellite-based estimates of groundwater depletion in India. *Nature* 460:999–1002.

Rogers, Peter, Radhika de Silva, and Ramesh Bhatia. 2002. Water is an economic good: How to use prices to promote equity, efficiency, and sustainability. *Water Policy* 4:1–17.

Sánchez-Azofeifa, G. A., A. Pfaff, J. A. Robalino, and J. P. Boomhower. 2007. Costa Rica's payment for environmental services program: Intention, implementation, and impact. *Conservation Biology: Journal of the Society for Conservation Biology* 21:1165–73.

Schneider, Lambert et al. 2007. Is the CDM fulfilling its environmental and sustainable development objectives? An evaluation of the CDM and options for improvement. *Öko-Institut for Applied Ecology, Berlin* 248:1685–1703.

Scott, Christopher A., and Tushaar Shah. 2004. Groundwater overdraft reduction through agricultural energy policy: Insights from India and Mexico. *International Journal of Water Resources Development* 20:149–64.

Sekhri, Sheetal. 2012. Sustaining groundwater: Role of policy reforms in promoting conservation in India. In *India Policy Forum* vol. 9, ed. Shekhar Shah, Barry Bosworth, and Arvind Panagariya. Thousand Oaks, CA: Sage.

Sekhri, Sheetal, and Sriniketh Nagavarapu. 2013. Less is more? Implications of regulatory capture for natural resource depletion. Technical report, University of Virginia, Department of Economics.

Shah, Tushaar. 2007. The groundwater economy of south Asia: An assessment of size, significance and socio-ecological impacts. In *The agricultural groundwater revolution: Opportunities and threats to development*, ed. Mark Giordano and Karen G. Villholth, 7–36. Wallingford, UK: CABI.

———. 2010. *Taming the anarchy: Groundwater governance in South Asia*. Washington, DC: Resources for the Future.

Shah, Tushaar, Sonal Bhatt, R. K. Shah, and Jayesh Talati. 2008. Groundwater governance through electricity supply management: Assessing an innovative intervention in Gujarat, western India." *Agricultural Water Management* 95:1233–42.

Shah, Tushaar, Mark Giordano, and Aditi Mukherji. 2012. Political economy of the energy-groundwater nexus in India: Exploring issues and assessing policy options. *Hydrogeology Journal* 20:995–1006.

Tiwari, V. M., J. Wahr, and S. Swenson. 2009. Dwindling groundwater resources in northern India, from satellite gravity observations. *Geophysical Research Letters* 36:18.

Tsur, Yacov, and Ariel Dinar. 1997. The relative efficiency and implementation costs of alternative methods for pricing irrigation water. *World Bank Economic Review* 11:243–62.

Vörösmarty, Charles J., Pamela Green, Joseph Salisbury, and Richard B. Lammers. 2000. Global water resources: Vulnerability from climate change and population growth. *Science* 289:284.

Wada, Yoshihide, Ludovicus P. H. van Beek, Cheryl M. van Kempen, Josef W. T. M. Reckman, Slavek Vasak, and Marc F. P. Bierkens. 2010. Global depletion of groundwater resources. *Geophysical Research Letters* 37:20.

Wolak, Frank A. 2010. An experimental comparison of critical peak and hourly pricing: The powercentsdc program. Stanford University, Department of Economics.

World Bank. 1998. India: Water resources management sector review. Groundwater regulation and management report, Washington, DC.

World Water Commission. 2000. A water secure world: Vision for water, life and the environment: World Water Vision Commission Report. World Water Council, Marseille.