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Conservation credits

A pilot of financial incentives to reduce groundwater use in smallholder agriculture

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Conservation Credits: A Pilot of Financial Incentives to Reduce Groundwater Use in Smallholder Agriculture

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December 1, 2018

Abstract

We present the results of a pilot project studying the potential for "conservation credits," a program of financial incentives for voluntary reductions in groundwater extraction. Conservation credits may be a cost-effective policy tool in situations where water and energy are scarce but pricing of either is politically infeasible. Working with local partner organizations in Gujarat, India, we developed this intervention and then evaluated it in a small randomized trial among smallholder farmers in three villages. We find that conservation credits are logistically feasible: farmers were willing to participate, meters functioned properly, and we observed little evidence of tampering. While quantitative results are underpowered and imprecise, point estimates suggest the program may have had large effects on water use. A larger, fully-powered evaluation is needed to generate reliable evidence on the impacts and cost-effectiveness of conservation credits.

1 Introduction

Groundwater is a major source of irrigation and drinking water worldwide, especially for farmers in developing countries (Ministry of Agriculture of the Government of India, 2014). Unfortunately, falling groundwater levels are creating negative consequences in many regions. Depletion reduces water availability, raises the cost of further extraction, may harm water quality, and can increase poverty and conflict (Sekhri, 2014). Many regulatory tools are available to address this textbook common-pool resource problem, ranging from quantity

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restrictions and tradeable quotas to simple price instruments. Despite this, groundwater pumping is currently unregulated in much of the world, suggesting that a new approach could be helpful.

In this report, we present the outcomes of a pilot project in which we studied the potential of a new program of payments for reduced groundwater pumping, which we call "conservation credits." Conservation credits implement a price incentive without requiring the power of taxation. First, we developed this intervention, building on an earlier pilot of a similar program in another part of Gujarat and resolving some limitations identified by the authors (Fishman et al., 2016). Then, we evaluated it in a small randomized trial among 90 well-owning farmers in 3 villages in the Indian state of Gujarat during the winter of 2017-18. The basic research design is to (1) install meters on the groundwater pumps of all study participants, (2) offer payments for reduced pumping, relative to a benchmark quantity, to a randomly selected sub-sample of participants, and then (3) compare the quantity of groundwater extracted by these farmers to that of the rest of the sample (i.e., the control group).

This pilot demonstrates logistical feasibility of our intervention: farmers approached were overwhelmingly willing to participate in the study and install meters, the meters functioned properly, and we observed little evidence of tampering. While evaluation results are highly imprecise, point estimates are consistent with a large reduction in pumping hours in the treatment group. Because the pilot was not designed to have adequate statistical power, a larger, fully-powered evaluation is necessary to generate reliable evidence on the impacts and cost-effectiveness of conservation credits. However, the pilot will also help design this evaluation, as it yielded several improvements in intervention design, as well as preliminary data on pumping hours to inform sample size calculations.

Our intervention may be a promising policy tool in itself. By offering payments for voluntary conservation, we may be able to overcome constraints often faced in regulating common-pool resources in developing countries. One such constraint is weak enforcement capacity: In many areas, a natural regulator for groundwater would be the state-owned utility that provides the electricity used for pumping - but consumer-level metering is rare, and electricity theft is widespread (Antmann, 2009; Golden and Min, 2012; Northeast Group LLC, 2014). Another constraint is political concerns: Both high energy subsidies and open access to groundwater are often entrenched means of redistribution; in India, reform efforts are commonly met with forceful protests (Sovacool, 2017).

The conservation credits model may be able to relax these constraints in three ways. First, our program may be easier to enforce than electricity sales; both technical and institutional features of the program may make cheating both more difficult to do and easier to detect. Second, we do not attempt to interfere with existing de facto entitlements, unlike (for example) a new Pigouvian tax on groundwater consumption, instead offering payments relative to existing usage patterns.

We see two potential routes to scaling conservation credits. First, such a program could be adopted by interested nongovernmental organizations, since it provides a route to implement a price incentive without requiring the power of taxation. In this regard, conservation credits can be considered to be an example of payments for environmental services (PES) for resource conservation. Our intervention has the same basic structure as hundreds of programs designed to incentivized the provision of environmental services, ranging from increased forest or wetland cover to reduced input intensity in agriculture. Despite their prevalence, rigorous evaluation of the cost-effectiveness of these types of programs has been limited (see Pattanayak et al. (2010) and Börner et al. (2017) for reviews). Most existing evaluations use covariate matching and are unable to address selection bias, a particular concern for a voluntary program. The sole exception is Jayachandran et al. (2017), who use a randomized controlled trial to find that conditional payments to forest-owning households in Uganda reduce deforestation rates by 50 percent. Our study contributes to this literature by providing evidence on the feasibility of PES in a novel context: promoting irrigation efficiency in agriculture.

Second, conservation credits could be implemented by an electric utility in many contexts where the electricity used to pump groundwater is also unpriced. Even a budget-constrained utility may be willing to do so if the cost of the energy conserved is greater than the cost of the program. To evaluate the viability of this potential Pareto improvement, a future evaluation can compare these costs, test whether an electric utility could be enlisted to reduce groundwater consumption using conservation credits, and if not, calculate the minimum subsidy that would be required for conservation credits to yield net benefits. We contribute to evidence on the price response of electricity demand in developing countries, where policymakers face many decisions about sectoral investment and reform to which this parameter is an important input. Experimental and quasi-experimental studies are still limited, but a few have been conducted recently on rural households in Columbia (McRae, 2015), urban households in South Africa (Jack and Smith, 2016), and new grid connections in Kenya (Lee et al., 2018).

Besides direct scaling, a program of conservation credits can also provide a way to estimate the price elasticity of groundwater demand. Efficiently implementing any type of groundwater regulation requires knowledge of the demand for groundwater - a key input for which evidence is thin. Price variation is scarce for an open-access resource, so most previous estimates have used proxies for the cost of pumping (Gonzalez-Alvarez et al., 2006;

Hendricks and Peterson, 2012), but these proxies may be correlated with other determinants of groundwater demand. Bruno (2018) exploits panel variation in prices across three regions of an irrigation district in California, but there is still a possibility that these prices may have responded to groundwater consumption; an experiment can rule out both concerns. Evidence on groundwater demand in developing countries is particularly scarce. Meenakshi et al. (2013) use differences-in-differences to study a phased-in switch to metering in West Bengal, India, but they rely on self-reported pumping data and find imprecise results. Badiani and Jessoe (2017) estimate an aggregate price elasticity using panel variation in the fixed cost of an electricity connection, but marginal incentives may produce quite different results.

2 Background

2.1 Optimal groundwater policy: A framework

In this section we present a basic economic model to analyze groundwater policy. Groundwater is a shared, common-pool resource. Extraction by one user (most often irrigators) imposes an externality on other users in the form of lower water availability and higher costs of extraction. Multiple regulatory tools - including both quantity and price instruments - are available to reduce over-extraction and restore efficiency, and demand for groundwater is an essential input to all of them. In this section we show how the optimal Pigouvian price level is set, and how this calculation is affected by the demand for groundwater. We focus on price regulation because our study implements a type of price instrument, but the analysis would be similar for the quantity instruments more frequently used for groundwater management.

Figure 1 illustrates consequences of price regulation in the presence of groundwater externalities. Irrigators have aggregate inverse demand for groundwater as a function of water quantity, $D(q)$. Inverse demand equals private marginal benefits net of private marginal costs of extraction; it first declines with quantity but eventually slopes upward as marginal costs rise. Extraction generates social marginal damages, $SMD(q)$, which increases with quantity. Although this analysis represents the situation at a single point in time, it can fully incorporate dynamics: the present discounted value of future costs of today's extraction may be included in demand (the internalized portion) and social marginal damages (the remainder).

When groundwater extraction has a price of zero, irrigators continue using water until net private marginal benefits are zero - where the demand curve intersects the x-axis, or q_0. This level of extraction is inefficient, since the social marginal damages are greater than the net private marginal benefits. The efficient level of extraction, instead, is found where these two curves intersect, or q^*.

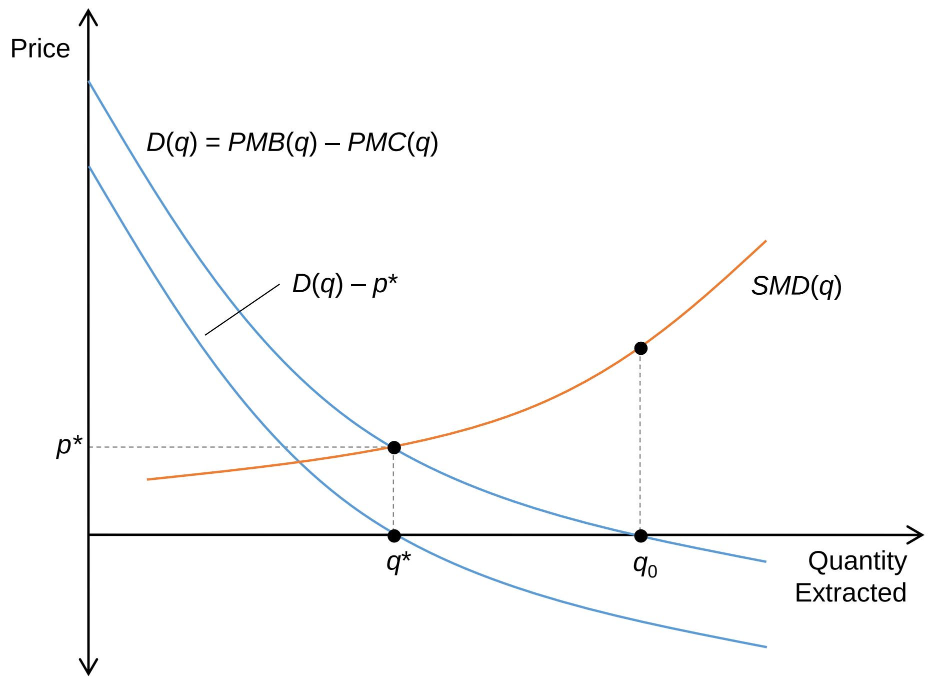

Figure 1: Price regulation for groundwater management.

This figure shows how price regulation can be used to achieve the optimal groundwater quantity extracted. Inverse demand for groundwater $D(q)$ is the difference between private marginal benefits $PMB(q)$ and private marginal costs $PMC(q)$; groundwater extraction also creates social marginal damages $SMD(q)$. Without regulation (i.e., at a price of zero), irrigators will consume the amount where demand meets the x-axis, q_0. When the price is set to p^*, the value of social marginal damages when it equals demand, irrigators will internalize the social damages, shifting effective demand down such that they instead consume the optimal quantity q^*.

One way to achieve this allocation is through a price, or tax, per unit quantity extracted. If the price p is set to equal p^*, the value of social marginal damages at q^*, irrigators will fully internalize the externality of extraction, shifting down the effective demand curve. Then, they will extract only up to the efficient quantity q^*, since net private marginal benefits including the tax are zero. To set this per-unit price p^*, a common heuristic is to set the price equal to the social marginal damages as measured locally. If social marginal damages are constant, the slope of demand does not matter, since the efficient quantity is simply whatever amount results from this price.

However, there are two reasons a policymaker pursuing price regulation may need to know the full shape of the groundwater demand curve. First, social marginal damages may not be constant. In Figure 1, if the price were set at $SMD(q_0)$, the resulting quantity extracted would be far too low. Constant social marginal damages may be a reasonable approximation over the range of groundwater conserved in small programs in large aquifers, but the slope of the demand curve is essential for larger programs or smaller aquifers. Second, even if social marginal damages are constant, the process of enacting a new policy may incur costs (such as political or administrative costs). Whether the policy is worthwhile depends on the quantity of water conserved, which can only be predicted with knowledge of the demand curve.

2.2 Existing evidence: Costs, benefits, and damages of groundwater extraction in irrigated agriculture

Existing evidence is relatively thin for both the social damages and demand functions for groundwater extraction. Social damages are difficult to quantify overall, but the components are well understood. Some components have known values, while others are best estimated using scientific models. Demand for groundwater, which is the difference between private marginal benefits and private marginal costs, is less well understood. Private marginal costs can be modeled fairly easily, but private marginal benefits are unknown. An evaluation of conservation credits could help fill this gap in knowledge by directly estimating demand.

2.2.1 Social damages

Social damages from groundwater extraction come first through the depletion of the resource. Groundwater extraction by one user generally leads directly to a decline in water levels for other users. The precise relationship between extraction and water levels depends on geology, topography, soil, rainfall, and climate. Deeper groundwater levels raise the cost of extraction, which can lead to increases in poverty and conflict (Sekhri (2014)). Depletion can also degrade water quality, either through inherent local properties of soil and geology, or by drawing in seawater from the ocean in coastal areas.

These externalities can be complex and difficult to estimate, since the spatial extent of the extraction externality varies greatly across locations. Depending on geology, in some areas, the externality may fall almost entirely on a small group of neighbors, in which case Coasian bargaining may sometimes be able to govern the aquifer efficiently. However, in many areas, and especially over longer periods of time, the externality is felt over a very large area, making local cooperation less likely to be sustained.

Another major source of social damages, which is easier to measure, is the costs associated with the energy required to pump groundwater to the surface. Typical energy sources are electricity and diesel, both of which create greenhouse gases and air pollution. In many developing countries, including almost all states of India, political pressure constrains governments to provide electricity to agricultural customers at a marginal price of zero. In this case, the social marginal damages of groundwater extraction include the marginal cost of electricity provision by the electric utility.

2.2.2 Demand

Private marginal costs in the short run can be modeled reasonably easily: they depend on the price of fuel (which may be zero), water levels, and pump characteristics. In the long run - that is, over large changes in water levels - discontinuities in private marginal costs may arise from deepening wells or purchasing new pump hardware.

Private marginal benefits of groundwater extraction are more difficult to estimate since they depend on the agricultural production function and any non-profit-maximizing behavior by farmers. Anecdotal evidence suggests that, especially in developing countries, water inputs often exceed yield- and profit-maximizing levels. Instead of measuring inputs precisely, some farmers simply flood their fields - which would suggest that private marginal benefits are low at the current equilibrium. Because these private benefits are difficult to model, we instead propose to directly estimate groundwater demand using a revealed-preference approach, observing how quantity extracted changes with price.

2.3 Conservation credits as a Pigouvian tax

Conservation credits allow us to estimate groundwater demand by varying the price of extraction. Because we cannot require irrigators to pay a tax. Instead, we offer payments for reduced water extraction, relative to a benchmark amount - an intervention called "conservation credits." This intervention provides the same marginal incentives as a Pigouvian tax, at least for some participants.

Figure 2 illustrates the budget set of the conservation credits contract. Two thresholds are set: a benchmark, and a maximum payment. If the irrigator extracts a greater quantity than the benchmark, the payment is zero. If the irrigator conserves water relative to the benchmark, the payment equals the price times the difference between the quantity and the benchmark. If the irrigator conserves very large amounts of water, the maximum payment may be reached, after which further conservation does not increase the payment.

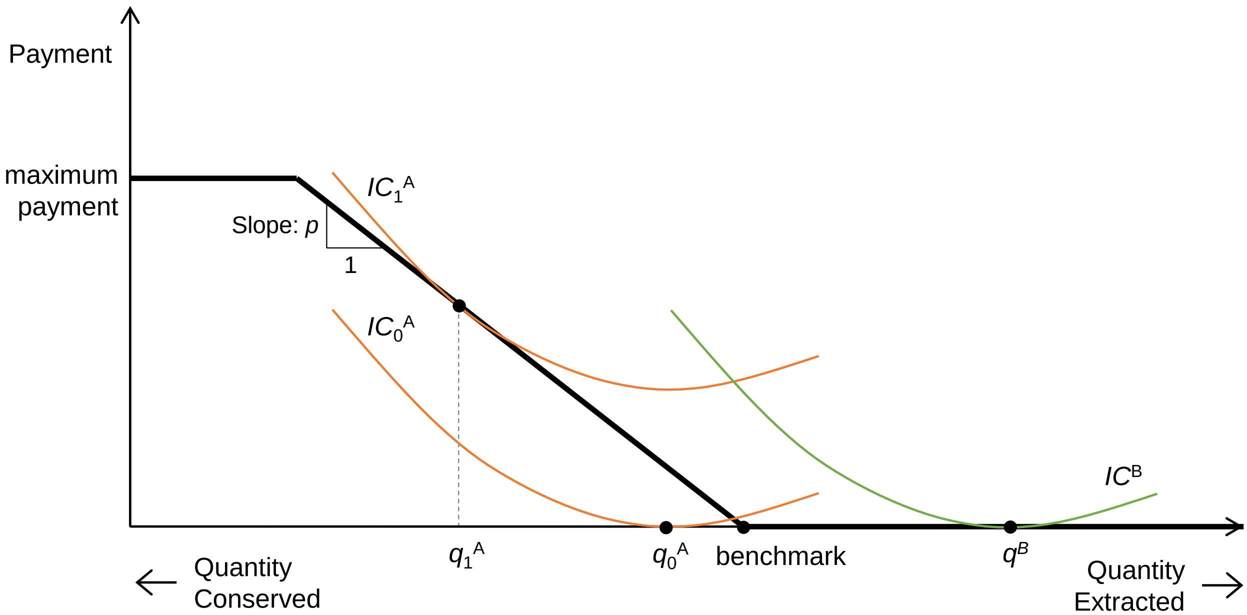

Figure 2: Budget set of conservation credits.

This figure shows the general form of the budget set created by a conservation credit program, along with indifference curves of two representative participants. The payment equals the price p times the quantity units conserved below the benchmark, up to a maximum payment. Irrigator A is marginal and will respond to the program by reducing quantity extracted. Irrigator B is extra-marginal, and does not change quantity extraction in response to the program.

Under a Pigouvian tax, all irrigators are marginal to the incentive, in the sense that any positive quantity extracted is subject to a per-unit price. Under conservation credits, many irrigators are marginal, but not all. To see this, Figure 2 plots quasi-linear indifference curves over groundwater extraction (including both the private benefits and costs) and payments of conservation credits. Without conservation credits, the budget set is flat and coincides with the x-axis; with conservation credits, the budget set is piecewise linear. Irrigator A is marginal: her indifference curves are tangent to the x-axis at q_0^A and tangent to the conservation credits budget set at q_1^A, indicating that she will reduce groundwater extraction when eligible for conservation credits. Irrigator B is extra-marginal: his indifference curves are tangent to both budget sets at q_B, indicating that he will not reduce extraction in response to conservation credits.

3 Pilot Design

We implemented a small randomized controlled trial among groundwater-irrigating farmers in Gujarat, India. The trial had two treatment arms: *Conservation Credit* farmers were eligible to receive payments for conserving groundwater below a benchmark, whereas *Control* farmers received no such incentives. Meters were installed for farmers in both groups to monitor groundwater pumping.

3.1 Sample

Setting Our trial was implemented in Saurashtra, a water-scarce region of Gujarat state, India. The study villages were located in Khambhalia block of Devbhoomi Dwarka district, where falling groundwater levels lead not only to increased irrigation costs, but also to increased risk of seawater intrusion into the freshwater aquifer.

Sample Selection We recruited our sample from three study villages. The study villages were selected by our implementing partners, the Coastal Salinity Prevention Cell (CSPC) and the Aga Khan Rural Support Programme (AKRSP), based on a combination of suitability criteria and logistical convenience (see Appendix A).

In each of the three villages, a sample of 30 farmers was drawn using a multi-step process that yielded a stratified random sample of all eligible farmers in each village. The eligibility criteria were a list of six questions aiming to ensure we selected farmers who (a) irrigated using groundwater and an electric pump, (b) did not share their well with other farmers, and (c) were willing to have a meter installed (see Appendix A for details).

3.2 Randomization

We divided the sample equally between treatment and control groups. Assignment was stratified by village and forecasted hours of irrigation, which we call benchmarks. We calculated benchmarks for all farmers on the basis of a baseline survey, and then divided the final sample within each village into above- and below-median benchmarks. This created two equally-sized cells in each village. Farmers in each cell were then assigned to groups using a pseudo-random number generator (Stata software). We also ran a concurrent, cross-randomized trial of another intervention, subsidies for micro-irrigation technology; Appendix A describes the details of the overall randomization procedure.

3.3 Interventions

For each farmer in the sample, we installed an electric hours-of-use meter on the pump in the well they identified as their primary source of groundwater for irrigation. Hours-of-use meters record the cumulative number of hours that the meter has been operated. Meters were installed by a local electrician and placed next to the pump starter; if the starter was not housed within a shed, the meter was covered with plastic to shield it from dust and rain.

Conservation Credits Farmers were incentivized for conserving water for four months of the Rabi season, from November through February. This is the period of peak irrigation in Gujarat; as there is typically no rainfall during Rabi, agriculture is entirely dependent on irrigation. Agriculture is predominantly rainfed during the Kharif season from June to September and rare during the hot, dry summer season from March to May. For each month, we set individualized benchmark amounts and then read the meters. If the farmer's pumping hours for that month were less than the benchmark, the farmer received a small payment for each hour pumped less than the benchmark. Payments were awarded according to the formula:

$$\text{Payment}_{it} = \max\left(0, \text{price}_i \times ((\text{hours benchmark})_{it} - (\text{hours consumed})_{it})\right) \tag{1}$$

where price_i is the per-hour incentive rate, $(\text{hours benchmark})_{it}$ is an individual-month-specific benchmark, and $(\text{hours consumed})_{it}$ is the monthly meter reading.

The price was set at 20 INR (0.31 USD) per hour of conserved pumping. This rate was chosen to be a realistic estimate of the groundwater price that a policymaker might wish to set: slightly lower than the unsubsidized cost of electricity supply in Gujarat for the power rating of a typical pumpset in the pilot region.[1] For the typical pumpset, this rate is also higher than the payments offered in the study by Fishman et al. (2016).

Benchmarks Benchmarks were set to approximate actual typical water consumption by each farmer. This is because the goal of conservation credits is to encourage farmers to reduce consumption relative to current pumping levels. To set overall benchmarks for the season, we took the average of benchmarks calculated via two methods: (1) an individual-history benchmark, in which irrigation hours in the previous year's Rabi season were calculated from self-reported answers to survey questions, and (2) a model-based benchmark, in which we predicted hours consumed using baseline data on farm and hydrological characteristics. To set monthly benchmarks, we divided total seasonal benchmarks equally across the number of months of the season. (Details of benchmark calculations are given in Appendix B.)

Control Participants in the Control arm also had an hours-of-use meter installed and read monthly. However, although hypothetical banchmarks were chosen for these farmers, they were not incentivized for conservation.

[1]That is: (5 INR/kWh average cost of electricity provision in Gujarat) * (6.2 HP average pump brake power) / (74% typical motor efficiency) * (0.75 kW/HP conversion factor) $\sim$ 31 INR/hr.

Initial intervention visits At the beginning of the trial, research and partner staff visited each farmer in the sample. Control group farmers were simply notified they were not selected for the program. Treatment group farmers were informed of their eligibility, given an explanation of program rules, quizzed on how to calculate potential payments, and corrected as necessary. They were also informed of their first benchmark, which was written on both a paper form handed to the farmer and a laminated form posted next to the meter, along with examples of payment amounts for various possible end-of-month meter readings.

Payment calculation and disbursement Partner staff visited each farmer once per month, in approximately 31-day intervals. During each visit, the the meter reading was recorded, the payment amount was automatically calculated and told to the farmer, and the next month's benchmark was told to the farmer and again written on both paper and laminated forms. Partner staff delivered payments in the form of checks within several days. Details of these visits and the disbursement process are in Appendix A.

4 Data

4.1 Data collection

We collected three datasets for all study participants: direct measurements of groundwater pumping, a baseline survey, and an endline survey. Although these surveys are unable to support strong conclusions due to the small sample size, they allowed us to gather preliminary evidence and helped us develop, pilot, and refine the survey instruments in preparation for future research.

We measured groundwater pumping using the hours-of-use meters installed on the pump starter of each participant's primary irrigation source. The cumulative reading on the meter was recorded by partner extension workers each month using a digital tablet survey. Data quality was verified through random audits, in which the digitally recorded meter readings were compared with dated, geo-located photographs of the meter dial taken as part of the tablet survey. Because we installed meters approximately one month before introducing the conservation credits program, we have one month of pre-intervention meter data and four months of post-intervention data.

Prior to randomizing participants into treatments, we conducted a comprehensive baseline survey. This survey included both an interview module (to gather self-reported information from the primary agricultural decision-maker) and a field module (for direct observations and measurements). Interview data included socioeconomic characteristics such as landholding size and household size; cropping, crop management, and irrigation decisions in previous years; characteristics and histories of irrigation wells; crop revenues and farm expenditures;

pumpset power ratings; and water conservation strategies and attitudes. Field measurements included the precise geolocation, depth to water table, and salinity levels (i.e., total dissolved solids) of each well on the participant's largest farm. All data was collected electronically through tablet surveys.

Following the end of the main irrigation season, we conducted an endline survey, also using an electronic tablet. The endline survey also included interview and field modules, including sections on micro-irrigation usage and water conservation practices, cropping decisions for the past season, irrigation behavior, self-reported responses to the program and attitudes about it, and well measurements.

4.2 Pumping duration

To assess the response of groundwater irrigation to water prices, our primary outcome is monthly hours of groundwater irrigation. Hours of irrigation during each meter-reading period is calculated as the difference between total hours consumed at the end and beginning of the period. For individuals whose meters have been disconnected following the drying of a well, hours are recorded as usual (i.e. according to the meter dial). For individuals whose meters are otherwise tampered with (e.g. if the meter is disconnected or broken but the well is not dry), hours are recorded as missing. Because meter-reading periods may vary slightly over time and across individuals, we normalize the measured hours of irrigation in each period by the number of days in the period.

As a first look at the data, Figure 3 presents a histogram of all observed monthly measurements of pumping duration. The variance is larger than initially expected, which will affect power calculations for future evaluations.

4.3 Balance and Attrition

In a small sample, it is possible that although treatment is randomized, the treatment and control groups will not be similar by chance. Encouragingly, the treatment and control groups are balanced across observable characteristics; Table 1 shows that there is no evidence that underlying differences might lead the two groups to use groundwater differentially.

Although the farmers assigned to treatment were similar at baseline, Table 2 shows that some farmers disconnected their meters, and that this practice was much more common in the control group. In particular, Panel A shows that although initially farmers in all groups kept their meters connected, from December onward the fraction of farmers whose meters remained connected was significantly higher in the treatment Group.

We believe the differential meter selection is due to control-group farmers disconnecting their meters after their wells went dry and they were no longer pumping water, whereas Conservation Credit farmers left their meters connected. When asked why they disconnected

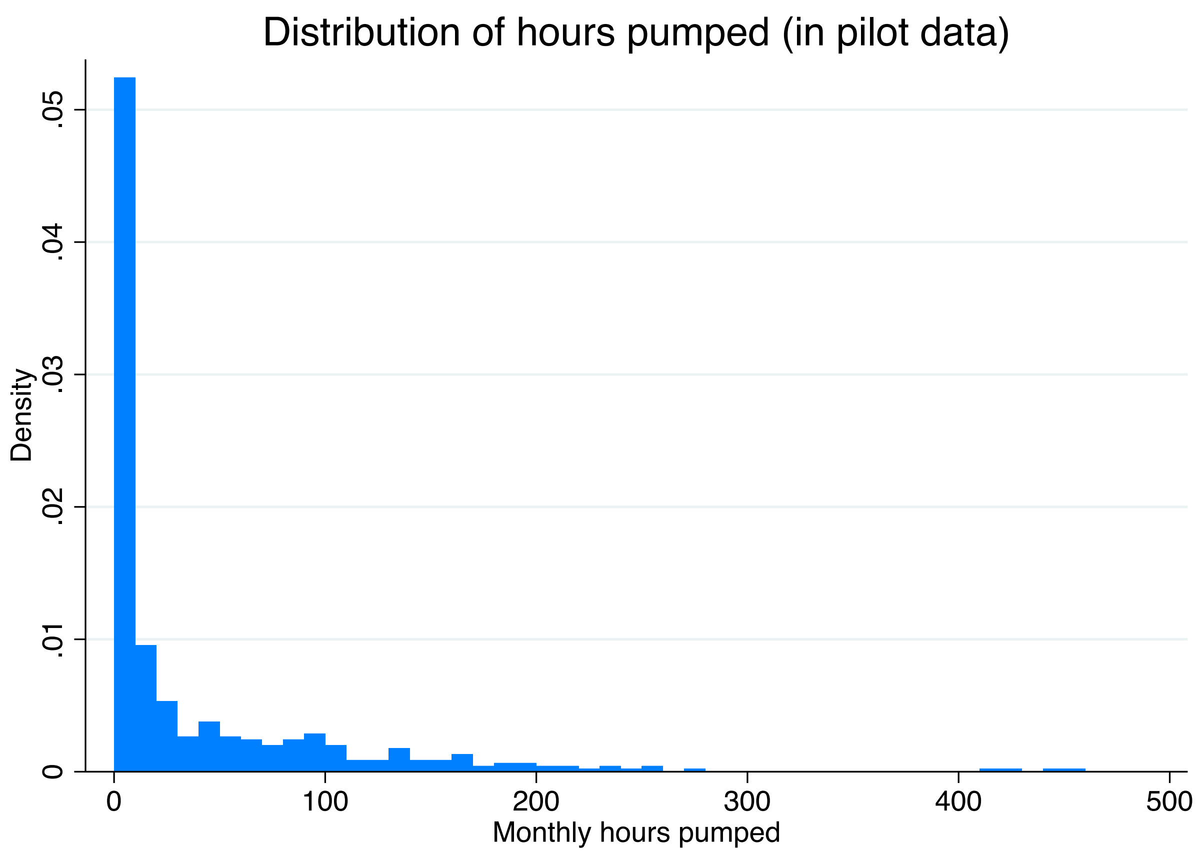

Figure 3: Distribution of monthly hours of groundwater irrigation, pooled across months

Notes: This figure plots the histogram of the monthly hours of groundwater irrigation measured in the 2017-2018 Rabi season (October-February) among the 90 pilot-study farmers Khambaliya, Gujarat.

Table 1: Baseline summary statistics are balanced across treatment groups.

	Full Sample	Control	Conservation Credits	Difference between Groups	p value
A. Demographics					
Household (HH) size	6.27	6.07	6.47	0.40	.381
	(2.15)	(2.02)	(2.28)		
Private water source	.87	.87	.87	0.00	1
	(.34)	(.34)	(.34)		
Indoor electricity connection	.88	.89	.87	-0.02	.751
	(.33)	(.32)	(.34)		
Age of head of HH	51.41	48.42	54.27	5.85	.5
	(40.37)	(15.28)	(54.61)		
Literate head of HH	.78	.84	.72	-0.12	.316
	(.42)	(.37)	(.46)		
B. Farm Details					
Farm area (ha)	2.84	3.1	2.58	-0.52	.166
	(1.75)	(2.17)	(1.17)		
Agricultural electricity connection	.94	.91	.98	0.07	.171
	(.23)	(.29)	(.15)		
Pump power (hp)	6.2	6.38	6.02	-0.35	.252
	(1.45)	(1.39)	(1.49)		
No. active wells	1.67	1.78	1.56	-0.22	.161
	(.75)	(.85)	(.62)		
Average Total Dissolved Solids (TDS)	518.95	533.56	504.69	-28.87	.547
	(216.35)	(266.88)	(153.95)		
C. Water Conservaton					
Ever used drip	.18	.18	.18	0.00	1
	(.38)	(.39)	(.39)		
Ever used sprinkler	.41	.38	.44	0.07	.526
	(.49)	(.49)	(.5)		
F-test for Joint Orthogonality					
F-statistic				0.53	
Sample size					
Number of individuals	90	45	45	90	

Notes: This table shows the average characteristics in the full experimental sample, together and for each treatment group. The p-values individually test that the difference between the treatment and control groups is zero for each characteristic. The F-statistic tests the joint hypothesis that the between-group differences of all characteristics are zero.

their meters, farmers uniformly reported that their wells had gone dry. It is therefore not surprising that disconnections were lower in the treatment group: these farmers received payments for low meter readings if their meters were connected, generating a particularly large incentive to maintain connection in periods without pumping. In the control group, in periods without pumping, there was no reason to keep the meter connected. We cannot observe exactly when pumping stops, but after it has stopped it tends not to restart.

To confirm this quantitatively, we regress whether the pump for each farmer in each month is connected on a treatment indicator, whether or not pumping had already ceased the previous month, and their interaction. The results are shown in Panel B. The positive interaction coefficient indicates that the differential meter disconnection is in large part driven by the differential response to wells going dry in the previous month: treatment farmers are more likely to keep their pump connected even if their well has no water, likely in order to receive payments. The remaining difference in meter disconnections is most likely due to wells going dry in the same month of disconnection (which we are unable to observe). We therefore assume that pumping hours are zero in months when the meter was disconnected. If anything, this will bias our treatment effects downward.

5 Pilot Results

Our analysis proceeds in two steps. First, we report evidence on how individuals respond to groundwater prices through intent-to-treat (ITT) analysis of the conservation credits intervention as a whole. Second, we estimate a model of demand for groundwater irrigation, using the price variation induced by our experiment in an instrumental variables strategy. While the pilot has low statistical power and cannot yield precise results, our analysis is consistent with Conservation Credits reducing groundwater use, and the magnitude of the effect is potentially large.

5.1 Intent-to-treat Estimates

Figure 4 plots the mean number of hours pumped per month of the pilot by treatment group. Before the price incentive was introduced, farmers in the treatment group pumped for slightly more hours on average than those in control. After conservation credits began, the treatment group pumped for fewer hours than the control group in every month of the intervention – although none of these differences are statistically significant.

We next report intent-to-treat (ITT) estimates of the effects of the conservation credits intervention. These estimates can be interpreted as a reduced-form measure of whether individuals respond to water prices. We use ordinary least squares to estimate a monthly

Table 2: Differential attrition by treatment group driven by dry wells.

	Differential meter Connection			
A. Meter connected, by treatment status				
	Full Sample	Control	Conservation Credits	p-value: Diff
Meter connected	0.861	0.789	0.933	0.01
Nov 17	0.989	1.000	0.978	0.32
Dec 17	0.844	0.778	0.911	0.08
Jan 18	0.800	0.689	0.911	0.01
Feb 18	0.811	0.689	0.933	0.00
B. Meter disconnections after discontinued pumping: Control and Treatment				
	Full Sample			
Cons. Credits	0.1***	0.2***	0.10*	
	(0.04)	(0.04)	(0.05)	
No consumption last connected period		-0.3***	-0.4***	
		(0.04)	(0.06)	
Cons. Credits X No consumption			0.3***	
			(0.09)	
Sample size				
Observations	360	360	360	

Notes: Panel A shows the fraction of farmers whose meters remain connected; it is higher in the Conservation Credit Group from December onward. Panel B shows the results from regressing whether the pump for each farmer in each month is connected on treatment, whether or not pumping had already ceased the previous month (columns 2 and 3 only), and their interaction (column 3 only). The positive interaction coefficient indicates that the differential attrition is in large part driven by the differential response to wells going dry: Conservation Credits farmers are more likely to keep their pump connected even if their well has no water, likely in order to receive payments.

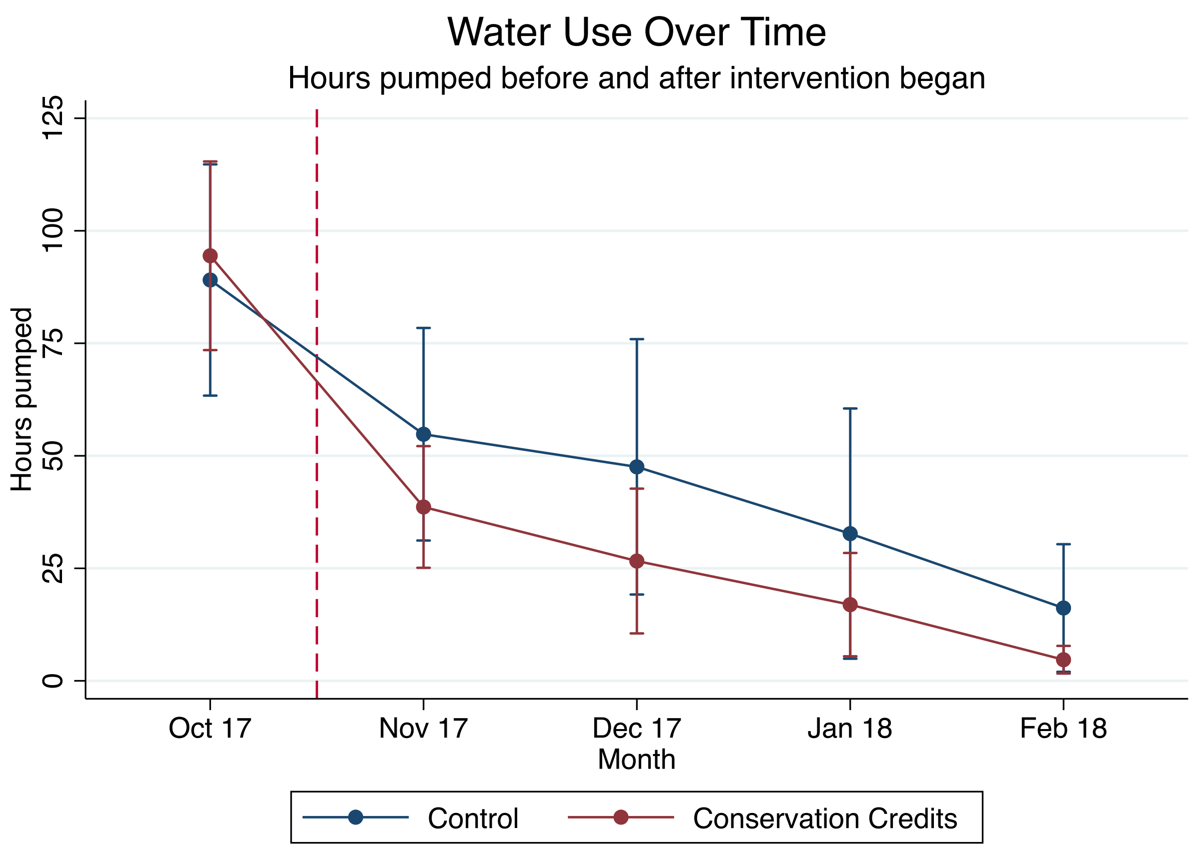

Figure 4: Event Study

Notes: This figure plots the average monthly hours of groundwater irrigation among farmers in our pilot experiment over the winter 2017-2018 program. The bars denote the standard errors of the mean.

panel regression of the following form:

$$Y_{it} = \alpha + \beta(\text{Conservation Credits})_i + X_i'\gamma + \mu_t + \varepsilon_{it}, \tag{2}$$

where Y_{it} is hours of pump operation meter reading for farmer i in month t, $(\text{Conservation Credits})_i$ is an indicator for being in one of the conservation treatment groups, μ_t are month fixed effects, and X_i is a vector of individual-specific covariates.

Table 3: ITT effect of conservation credits program in pilot.

	Monthly Pumping Hours				
	(1)	(2)	(3)	(4)	(5)
Conservation Credit treatment group	-11.867	-11.828	-14.179	-12.718	-17.690
	(10.043)	(9.446)	(10.709)	(12.602)	(12.753)
Strata FE		X	X	X	X
Month FE			X		X
Sub-village FE			X		X
Baseline controls				X	X
Observations	360	360	360	344	344
Clusters	90	90	90	86	86
Mean Control Hours/Month	33	33	33	33	33

Standard errors clustered by individual.

Table 3 shows the results these linear regressions, with each column including a different set of covariates. Point estimates suggest that eligibility for conservation credits induces a practically large reduction in pumping hours: a 36 percent decrease on a control-group mean of 33 hours per month. Although these point estimates are imprecise (confidence intervals include both zero and some positive values), they appear to be stable across specifications.

5.2 Demand estimation via IV

Our experimental design allows us to identify the slope of groundwater demand with respect to price, a parameter that is an important input to the design of any type of groundwater regulation. We specify groundwater demand using the following form:

$$Y_{it} = \alpha + \beta p_{it} + \mu_s + \varepsilon_{it} \tag{3}$$

where $p_{it} \in \{0, 20\}$ indicates the marginal cost of an hour of irrigation for farmer i in month t, and μ_s is a vector of strata fixed effects. We examine two variations of this demand specification. In the first, the outcome variable Y_{it} is the hours of pump operation as measured in meter readings, yielding a simple linear demand function. We also consider the natural log of the monthly hours + 1, which can be interpreted similarly to a log-linear demand function.

We estimate Equation 3 by two-stage least squares to correct for endogeneity in price. Note that while Control farmers always face a price of 0, Conservation Credits farmers face a price of either 0 or 20 depending on whether their consumption is above or below their benchmark. This introduces endogeneity into Equation 3: in the Conservation Credit treatment, positive consumption shocks ε_{it} are mechanically correlated with zero prices, biasing OLS estimates of β downward.

Columns 4 and 5 of Table 4 show estimates of β for the linear and log-linear specifications of Equation 3. These estimates can be interpreted as a local average treatment effect of our experimental price variation on those farmers whose marginal consumption is priced.[2] The first stage is strong, showing that many farmers in the Conservation Credit treatment group faced positive marginal prices for groundwater. The point estimates for demand are negative, showing that farmers who face higher marginal prices use less groundwater. However, again, due to the small size of the pilot, the standard errors are large and the coefficients are not statistically distinguishable from zero. A larger experiment will be required to understand the demand response more precisely.

Table 4: Demand estimation.

	OLS Demand		First Stage	IV Demand	
	(1) Linear	(2) Ln(Hrs+1)	(3) Price	(4) Linear	(5) Ln(Hrs+1)
Marginal price (INR/hr)	-1.222	0.007		-1.565	-0.016
	(0.322)	(0.012)		(1.224)	(0.037)
Conservation Credit treatment group			7.560		
			(0.847)		
Strata FE	X	X	X	X	X
Observations	360	360	360	360	360
Clusters	90	90	90	90	90
Implied Elasticity (price=20)				-1.51	-0.32

Standard errors clustered by individual.

Notes: This table shows the results of estimating Equation 3. Columns 1 and 2 use report the biased OLS demand estimates. Column 3 reports the first stage results from a regression of groundwater price on treatment assignment. Columns 4 and 5 report IV estimates of the slope of demand for groundwater.

[2] Our methodology is in the spirit of quasi-experimental estimates of the elasticity of taxable income from non-linear budget sets (as summarized by Saez et al., 2012) and of electricity demand (Ito, 2014).

5.3 Survey evidence

Mechanisms While our primary research aim is to quantify the price response of demand, it is also important to understand the mechanisms through which water use changes. This can both inform our expectations of how the intervention will fare in other settings, and shed light on the broader consequences of the policy. Following the intervention, we collected self-reported information to better understand the channels through which farmers in our study area conserve groundwater.

Farmers receiving conservation credits reported that they achieved water savings by reducing irrigation intensity and cultivating less crop area. Figure 5 shows that treatment group farmers were more likely than control group farmers to report having cultivated less area and irrigating for less time during each irrigation instance.

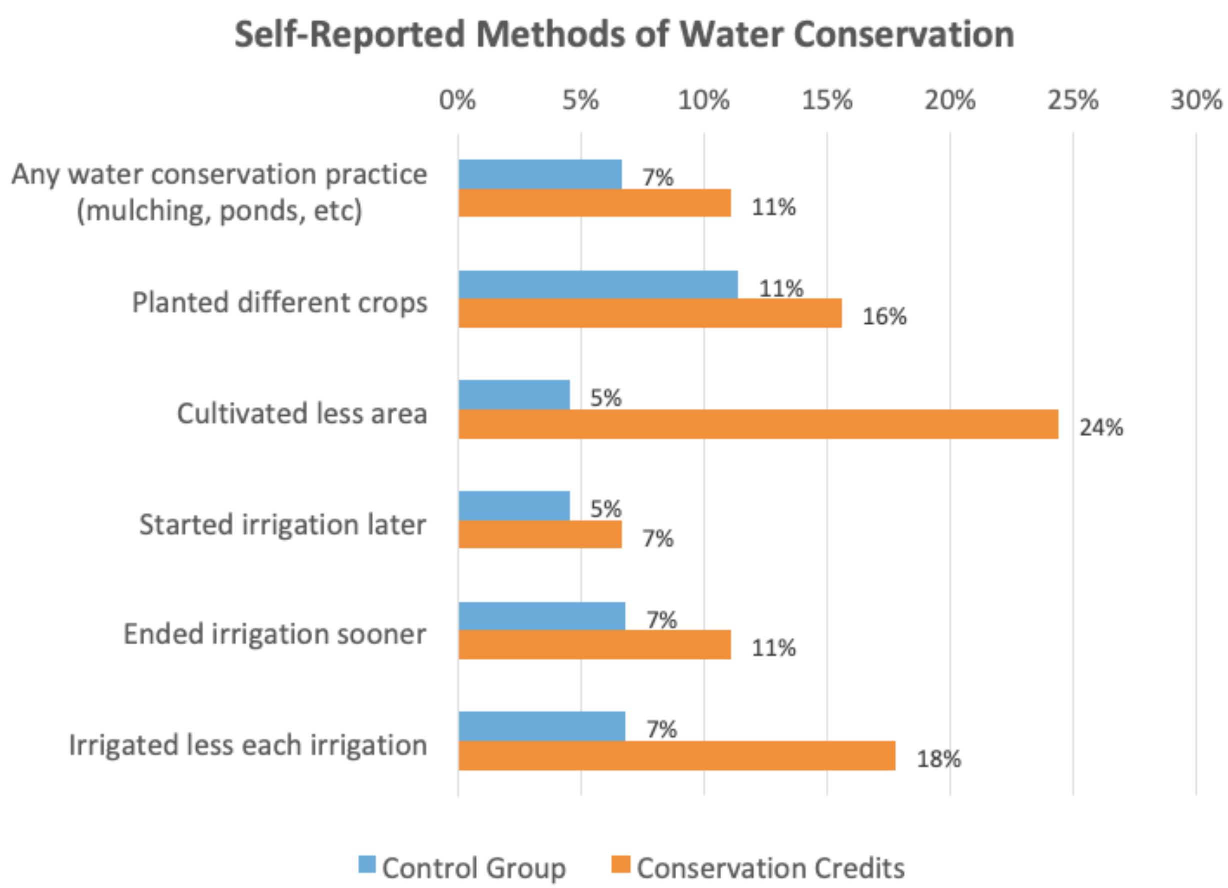

Figure 5: Self-reported water conservation behaviors at endline.

Attitudes We also asked farmers whether they agreed with each of a series of statements about the program. Figure 6 shows the percentage of farmers in the treatment and control groups who agreed with each statement. Note that for control group farmers, "the program" was limited to meter installation and meter readings, so the difference between treatment and control groups represents the reaction to being offered conservation credits.

Participating farmers overwhelmingly reported that they liked the program. Nearly all farmers agreed that the program was good for their village, and that they would like to see the program continued and expanded. The fact that 96-100% of farmers in both treatment and control groups expressed positive sentiments suggests that the individual randomization of conservation credits did not create conflict or resentment among farmers.

Besides these approval questions, many farmers reported that they checked the hours shown on the meter, and that the meter was useful for conserving water. As might be expected, these proportions were significantly higher for farmers receiving conservation credits. Some farmers in the treatment group reported that they believed their yields increased as a result of the program. However, this may not be reliable, since some farmers in the control group said their yields decreased - an unlikely result given that they only received meters.

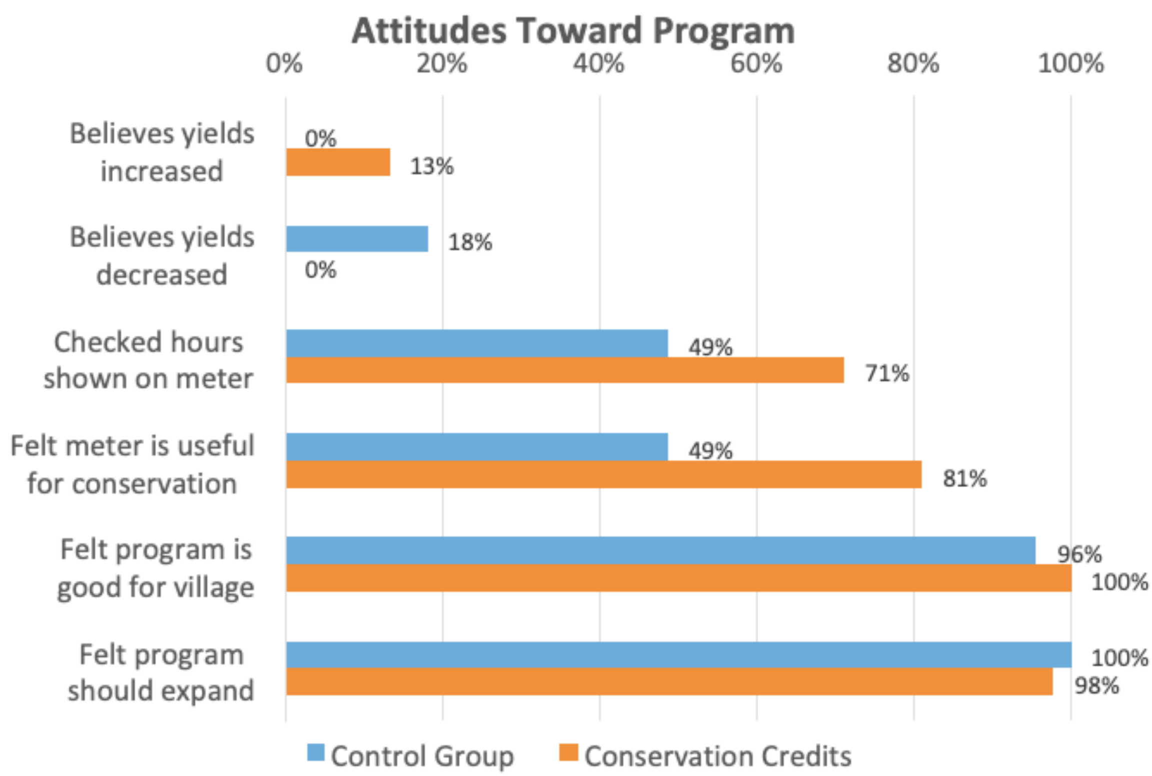

Figure 6: Self-reported atttitude toward the interventions at endline.

6 Lessons Learned

The primary aim of this pilot was to inform the design of a full-scale experiment in a similar area of Gujarat. The pilot has informed our experimental design in several ways.

6.1 Demonstrates logistical feasibility

The pilot shows that the intervention can be successfully implemented among a similar population as the experimental sample. First, farmers were broadly willing to participate, voluntarily accept hours-of-use meters and agree to monthly meter readings. Of 144 farmers randomly sampled from village rosters, 100% agreed to allow us to install a meter on their pump. Of 90 farmers meeting eligibility criteria, meters were successfully installed for 100%. Of the same group, one withdrew during the intervention, yielding a 99% completion rate.

Second, meters performed well, and meter tampering is difficult and appeared to be minimal. Meters worked well, incremented in expected ways, and experienced no noticeable performance problems. The meter itself is sealed, with no controls other than a reset button (which can be easily detected after a first reading). Disconnection is not simple and leaves indications in the form of uncoiled wires; only two farmers showed evidence of having disconnected and reconnected in the same month.

Third, farmers appear to understand the program; during the initial intervention visit, farmers were asked questions designed to measure comprehension and corrected if necessary; surveyors reported a subjective assessment that most farmers understood the program very well.

6.2 Improvements in intervention design

The pilot yielded several ideas for improving the conservation credits program that can be incorporated into future implementation.

First, farmers should be incentivized to keep their meters connected. In the pilot, we found that some farmers (20 percent) disconnected their meter following the last irrigation of the season. Disconnections threaten the fairness of the program, since it is difficult to know whether a farmer disconnected because they are truly no longer pumping, or in order to hide fraudulent pumping activity. In the pilot, we came to be confident that disconnections were overwhelmingly innocent, through conversations with farmers as well as the facts that (a) disconnections typically followed a month of zero or near-zero pumping, and (b) disconnections were highly concentrated among farmers in the control group, who had nothing to gain from disconnections. However, disconnections are still a barrier to accurate measurement of pumping duration.

To incentivize participants to keep their meters connected, we have three suggestions. One, enforce a connection requirement: If the meter of a farmer receiving conservation credits is found disconnected or tampered with, that farmer will be disqualified from receiving further payments. Two, offer a small financial incentive for keeping the meter connected through the end of the meter-reading period. Three, conduct random, unannounced checks of whether the meter is connected, in addition to regular monthly meter reading visits.

Second, the program could be more cost-effective by focusing on months and geographical regions in which the vast majority of farmers have access to groundwater (i.e., without deepening a well). In the pilot, 29 percent of meter readings showed zero consumption, a pattern that rose to 50 percent by the end of the pilot. Discussion with farmers revealed that many had stopped pumping because their well had gone dry. These zeros substantially reduced statistical power (by increasing the variance of the outcome variable), and paying farmers whose well had gone dry was perceived to be unfair by the implementing partner. Future implementations should consider choosing geographical regions that have more reliable water availability, and paying conservation credits during a more limited number of months (those in which a large majority of farmers are known to irrigate crops).

Third, the program could be most cost-effective by improving the benchmarks against which groundwater conservation is rewarded. In the pilot, we found that our benchmarks did not predict pumping hours very well. We suggest four ways by which benchmarks may be able to be improved. One, benchmarks could incorporate a long period of direct measurements of pumping prior to the introduction of conservation credits. With enough baseline data, benchmarks could be defined as a farmer's pumping hours during the same months in the prior year. Two, the benchmark model could incorporate electricity data. In the absence of directly measured pumping, a farmer's prior pumping could be estimated from data on electricity consumption, obtained from either the electric utility or by examining prior electricity bills. Three, our empirical model predicting pumping hours may be able to be improved through further analysis of our baseline and endline surveys, potentially including machine learning methods. Finally, benchmarks can also vary across months in way that track actual pumping patterns within the season. Data for this can be obtained from direct measurements of pumping hours from this pilot, irrigation calendars for the major crops grown in the region, and electricity consumption data.

6.3 Sample size calculations

Neither water consumption nor our proxy, hours of pump operation, is often measured at the farm level in India, and so our pilot measurements represent a contribution in themselves. These monthly measurements of pump operation time can inform power calculations for future evaluations. We calculate the conditional variance of total pumping hours as 0.43 (i.e., after partialing out several baseline covariates and dividing by the sample mean). This is fairly large and implies that large samples will be necessary to detect statistically significant effects of a conservation credits program. However, the variance may be able to be reduced by conditioning on more extensive baseline pumping data or by introducing additional sample selection rules to exclude participants that are likely to pump either zero or extremely large amounts.

7 Conclusion

This report presents the outcomes of a pilot study of payments for groundwater conservation in Gujarat, India. The pilot demonstrated proof of concept, showing that a program of conservation credits can be feasibly implemented by a third party (i.e., not an electric utility). While evaluation results are imprecise, point estimates are encouraging enough to justify a larger-scale implementation and evaluation of such a program.

We see two main routes to scaling conservation credits: either by a government agency or NGO with the goal of reducing groundwater consumption, or by an electric utility with the goal of reducing energy consumption in a politically acceptable manner. In both cases, a larger-scale randomized experiment would help evaluate the cost-effectiveness of direct financial incentives for reducing groundwater extraction.

As a path to sustainable groundwater management, conservation credits are more expensive than more typical policy proposals that involve cooperation among users within a basin. However, cooperation can be difficult to sustain when the impacts of groundwater depletion can extend far beyond a local area, and governments provide ongoing financial support for plenty of other activities that generate externalities (e.g., immunizations or education). Currently, the state government of Gujarat spends huge sums of money annually on subsidies for water-saving irrigation technology and on civil engineering projects to increase water supplies available to local communities. While conservation credits also may require ongoing expenditures, it is possible they are more cost-effective at improving water management than these existing programs. A larger-scale evaluation would provide a guide to how cost-effective conservation credits are and how they compare to these other programs.

Because groundwater conservation yields the side benefit of reduced electricity demand, a conservation credits program could also be implemented by an electric utility. A budget-constrained electric utility should be willing to implement such a program on its own if the cost of the program is less than the cost of the energy conserved. In a larger-scale evaluation, we could calculate the minimum marginal cost of electricity for which the program would be revenue-neutral at worst, so that utilities could compare this figure to their own costs and decide whether it would be worthwhile. We could also take estimates of actual marginal costs faced by electric utilities from the literature and test whether the program could in fact be implemented by a utility with a budget-balance constraint. Even if the answer is no, the government may still be willing to provide a subsidy on the basis of groundwater conservation, and so we could calculate the minimum subsidy that would have to be provided that would make conservation credits workable for the electric utility.

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A Implementation Details

A.1 Intervention design

In each of 3 villages, 30 well-owning farmers were selected for participation in the pilot study. These 90 farmers received hours-of-use meters to measure their groundwater pumping, these meters were read once per month for five months, and they were given baseline and endline surveys.

The conservation credits trial was embedded within a larger research design in which we cross-randomized eligibility for subsidies for micro-irrigation systems (MIS) such as drip and sprinkler irrigation technology. Conservation credits were randomized at the individual level: they were offered to half of the participating farmers in each village, randomly selected, with the other half serving as a control. MIS subsidies were randomized at both the village and individual level: subsidies were offered to all farmers in one village and none in another. In a third village, 20 participating farmers were selected to be individually eligible for MIS subsidies, with the rest of the village serving as a control. The purpose of this complex design was to pilot the logistical feasibility of individual-level MIS subsidies. The overall design of these treatment assignments is shown in Figure 7.

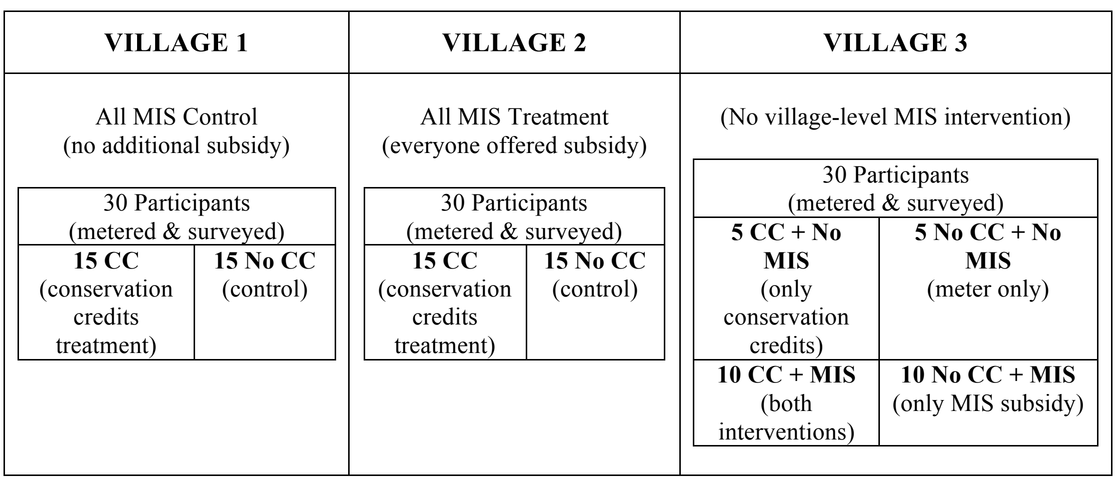

Figure 7: Treatment assignment

MIS subsidies. Farmers eligible for MIS subsidies were offered a flat-rate subsidy of Rs. 10,000 for purchasing a new drip irrigation system, or Rs. 2,800 for purchasing a new sprinkler irrigation system. Subsidy amounts were chosen to equal approximately 10% of the cost of a typical installation of each of these systems. CSPC and AKRSP chose a flat rate instead of a percentage to avoid giving larger subsidies to farmers with more land, who are likely wealthier. These subsidies were additional to MIS subsidies of up to 70% available through the Gujarat Green Revolution Company (GGRC).

Meters. For all participating farmers, an electric hours-of-use meter was installed on their primary groundwater pump. Hours-of-use meters record the cumulative number of hours that the pump has been operated. Other types of meters considered were electricity meters and water meters. Some farmers were resistant to electricity meters because they suspected they could be used for billing by the electric utility. Water meters were much more expensive, were difficult to fit properly given that farmers had heterogeneous pipe diameters, and were unreliable because they easily became clogged with debris.

The meter model selected was the Nishant Engineers NE53/6S. This model was selected after a search of meters for sale in India; it was the least expensive model that was able to be installed on Gujarat's agricultural electricity system. This model was also used in the study by Fishman et al. (2016) and recommended in personal communication with the authors.

A.2 Village selection and assignment

Criteria. Village selection criteria were developed by CPSC and the researchers, taking into account (a) CPSC program needs, (b) suitability for the research study, and (c) a desire to select villages that are somewhat "average" or representative of the larger population of coastal Saurashtra. The criteria were:

	General criteria	Specific criteria
1	Coastal Saurashtra, within reach of implementing partner	Porbandar or parts of Junagadh and Devbhoomi Dwarka districts.
2	Near coast	Located within 35 km of coastline.
3	No pre-existing partner activity	Not listed in CSPC village lists.
4	Not yet fully saline	Not classified as Fully Saline by CSPC.
5	Neither extremely small nor extremely large	Population between 100 and 10,000, and at least 50 households (2011 Census).
6	Groundwater is primary source of irrigation	More than half of irrigated land uses groundwater (in both 2011 Census and the average of 2001 & 2011 Censuses)
7	Enough recent MIS adopters	At least 10 GGRC beneficiaries in 2015-16, including at least 5 installing sprinklers.
8	Enough total prior MIS adopters	At least 10% of farmers, and 5% of households, have ever been GGRC beneficiaries.
9	High enough recent MIS adoption rate	At least 3.5% of both farmers and households were GGRC beneficiaries in 2015-16.
10	Not too many prior MIS adopters	No more than 67% of farmers, and 60% of households, have ever been GGRC beneficiaries.

Selection. After applying these criteria, 155 villages remained eligible. From these, AKRSP staff chose 3 villages for logistical convenience: Bhankhokri, Laluka, and Thakar Sherdi, all in Khambhalia block of Devbhoomi Dwarka district.

Treatment assignment. For the village-level MIS treatment, research staff arbitrarily assigned the villages to the three different treatment statuses:

- Village 1 (MIS Control): Bhankhokri.
- Village 2 (MIS Treatment): Laluka.
- Village 3 (Individual MIS Randomization): Thakar Sherdi.

A.3 Farmer selection and assignment

In each of the 3 pilot villages, 30 farmers were selected for participation. Farmers were selected through a multi-step process, consisting of village listing, stratified random sampling, eligibility screening, and consent. This process yielded a stratified random sample of all *eligible* farmers in each of the three villages. This means that farmers included in the pilot are representative of all farmers meeting the eligibility criteria (stated below) in the villages, but they are not necessarily perfectly representative of *all* farmers in their villages.

Village listing. In each village, AKRSP and research staff approached village leadership to understand the basic village set-up and number of village subdivisions, and asked for introductions to knowledgeable farmers in each subdivision. Together, farmers and staff noted down the names of all farmers in each subdivision, their contact information, and the number of bore wells and dug wells they own. The official village list was obtained from village leadership and cross-referenced to confirm this information.

Random sampling. From each village list, research staff generated a randomly-ordered priority list of farmers within each subdivision, prior to contacting them for eligibility screening.

Eligibility screening. Research staff contacted farmers by phone to briefly introduce the organization and asked six questions:

1. Do you irrigate your farm with groundwater?
2. Did you irrigate your farm in Rabi 2016-2017?
3. Does your irrigation water primarily come from an electric pump?
4. Does the pump have only one starter?
5. Are you the only user of the primary pump you use?
6. Are you willing to allow us to install an hours of use meter on this pump?

If the farmer answered "yes" to all six questions, the eligibility criteria were met, and the farmer was placed on the list of participants. If the farmer answered "no" to any question, the eligibility criteria were not met, and the farmer was excluded from the pilot.

Research staff continued down the priority list of farmers until the quota within each subdivision and village was filled. The result is a random sample of farmers meeting the eligibility criteria, with the sample stratified on subdivision and village.

Consent form. Following eligibility screening, research staff met with farmers and reviewed a consent form. The consent form explains, in a straightforward way, topics including:

- The purpose of the study, and the organizations and researchers conducting it.
- Why the individual was selected for the study.
- What the study entails (i.e., surveys and a possible intervention assigned by lottery).
- That participation is completely voluntary and the farmer may withdraw at any time.
- That individually-identifiable data from the study will remain confidential.

Farmers were asked to sign the consent form to indicate understanding and acceptance. Consent was a prerequisite to participation. The consent form, along with all surveys and research practices, was overseen by two ethics committees: the Committee on the Use of Humans as Experimental Subjects at MIT, and the Institutional Review Board at the Institute for Financial Management and Research (IFMR) in Chennai.

Treatment assignment. Within each village, 15 farmers were assigned to receive conservation credits (CC Treatment) and 15 were assigned to receive only a meter (CC Control). In the MIS individual randomization village (i.e., Thakar Sherdi), 10 of the each of the CC Treatment and CC Control farmers were assigned to be eligible for the additional MIS subsidy (MIS Treatment), while the remaining 5 in each CC group were assigned to be ineligible for the MIS subsidy (MIS Control).

Assignment was stratified by village and forecasted hours of irrigation (i.e., benchmarks). Specifically, the final sample within each village was divided into above- and below-median benchmarks, creating two equally-sized cells in each village. Farmers in each cell were then randomly assigned to the various treatment groups by researchers using a random number generator in computer software (Stata).

A.4 Rollout

Timeline. The timeline of pilot activities is described in Table 5.

Table 5: Pilot timeline.

Task	Date performed
Village listing	May 2017
Eligibility screening	June 2017
Baseline survey	July-August 2017
Meter installation	September 2017
CC intervention visits	October 2017
Meter readings & CC disbursement	November 2017 - February 2018
MIS village meetings	December 2017
MIS subsidy open	December 2017 - April 2018
Endline survey	March 2018

Meter installation. Hours-of-use meters were installed by a local electrician in coordination with AKRSP and research staff. Meters were connected to and placed next to the starter; if the starter was not housed within a shed, the meter was covered with plastic to shield it from dust and rain.

Village meetings. AKRSP and research staff developed and presented village meetings to support farmers with adequate information to make decisions about MIS adoption. In all three pilot villages, a through explanation was given on the costs and benefits of MIS, as well as the entire GGRC subsidy application process. Local MIS dealers, as well as representatives from the GGRC, were present at all three village meetings to help answer farmers' questions. In the MIS Treatment village (i.e., Laluka), all farmers were eligible for the MIS subsidy, and the presentation there marketed AKRSP's additional MIS subsidy. In the other two pilot villages, no mention was made about of this additional subsidy.

Intervention visits. For conservation credits, AKRSP and research staff together visited each farmer participating in the pilot. The visits were different between the treatment groups. Farmers not eligible for conservation credits were simply notified that they were not selected.

For farmers receiving conservation credits, staff members:

1. Informed farmers of their eligibility and gave an explanation of program rules.

2. Collected documents required to receive payments. These documents include: 1 copy of either a photo ID or Aadhar card, and a copy of a bank passbooks.

3. Recorded meter readings and informed farmers of their first benchmark.

4. Wrote the benchmark, along with examples of eligible payment amounts for different end-of-month meter readings, on both a paper form handed directly to the farmer and on a laminated form posted next to the meter.

5. At the end of the visit, quizzed farmers on their knowledge of the program and how to calculate their payments, and corrected them if necessary.

For MIS, farmers randomly selected for our MIS subsidy were informed via phone calls and door to door visits by the AKRSP Master EV, that they had been selected to receive an MIS subsidy.

Meter readings. Meter readings were performed monthly by the AKRSP extension volunteer (EV) using SurveyCTO software on a tablet. During these visits:

1. The EV recorded the meter reading, took a photo for data verification, and checked for foul activity.

2. Farmers receiving conservation credits were informed of their payment amount, automatically calculated by the tablet survey software. The EV wrote this amount on a voucher and obtained a signature from the farmer (or another household member).

3. Farmers receiving conservation credits were informed of their benchmark for the next month, also calculated by the software. The EV wrote the new benchmark on a new paper form, along with the farmer's name, the date of the next meter reading, and the current meter reading. The EV also updated the laminated info sheet posted next to the meter with the same information.

4. Farmers not receiving conservation credits received a different form, filled in only with their current meter reading and the EV's next return date.

Conservation credit disbursement process. Research staff worked with AKRSP to establish a disbursement process for conservation credits that meets AKRSP's internal finance policies and results in rapid, efficient payment disbursement.

1. During household visits farmers gave us copies of their bank passbooks and Adhaar card so we could write them payment checks in the future.

2. Payment vouchers were signed during monthly meter readings, a necessary step to ensure farmers were informed of their payment amount.

3. Following each round of meter readings, research staff prepared a data sheet containing the farmer names, IDs, last month's meter reading, this month's meter reading, last month's benchmark, number of creditable hours, and total payment. This form was sent to AKRSP digitally, along with a signed hard copy via mail.

4. Upon receiving the benchmark sheet, AKRSP produced a payroll sheet of all farmers receiving CC payments for the month.

5. Checks were written to eligible farmers who pumped below their benchmark, according to the amounts credited in the payment sheet.

6. Checks were then hand-delivered to eligible households by AKRSP staff. During this visit, farmer signatures were collected on a pre-filled registry, acknowledging the payment.

MIS application & disbursement process. Research staff also worked with AKRSP to develop a distribution system for MIS subsidies that integrates efficiently with existing GGRC application processes.

1. Village lists were double-checked against those of the Patwari/Talati/Village Accountant in each village to ensure they included farmer's Land Survey Number and Khata Number (land account number).

2. To receive the MIS subsidy, farmers present the following documents to an AKRSP staff member:

   - Aadhaar Card (or other photo ID)
   - Bank Passbook
   - Stamped/Signed GGRC Work Order
   - Payment Receipt from MIS Dealer
   - Land Survey Number

3. After verifying information in these documents, AKRSP staff members sign a check and inform the farmers of where to pick it up.

B Benchmark Calculations

To set season-total benchmarks, we combine two methods:

1. Individual History benchmark. This method calculates each farmer's total hours of pumping in the previous year (2016) using his answers to baseline survey questions. (This method takes into account a farmer's and typical use, but it may be inaccurate if the farmer does not report information accurately on the baseline survey.)

$$\text{Individual History Benchmark} = \Sigma_{p=1}^{P} \left(\text{Irrigations on Plot } p \times \text{Hours Pumped per Irrigation}\right) \quad (4)$$

2. Model-based benchmark. This method generates a prediction for each farmer's hours of pumping based on a few farmer characteristics. To do this, we create a statistical model, which will take into account the typical patterns of water pumping by farmers in the pilot region. (This method smooths any farmer-specific inaccuracies, but it also does not account for each farmer's specific situation.)

$$\text{Model-based Benchmark} = \text{Irrigated Area} \times \text{Pumpset Power Rating}^{b_1} \times \text{Water Depth}^{b_2} \times b_3 \quad (5)$$

Because each of these two methods has advantages and disadvantages, we take the midpoint (average) of the two methods to set the season total benchmark.

To translate season-total benchmarks into monthly benchmarks, we divide the season-total benchmarks across the number of months in the season (according to our Baseline survey).

Details: Individual-history benchmark

For each plot in Rabi 2016-17, we calculate total hours irrigated by three methods:

Method 1a: Product of irrigation instances and irrigation hours per day. The survey text used is: "How many times did you irrigate plot [plot number] in [season]?" x "During the [season] season, on a typical day that you irrigated plot [plot number], how many hours per day did you pump water?"

Method 1b: Product of irrigation weeks, irrigation days per week, and irrigation hours per day. The survey text used is: "For how many weeks during the [season] season, did you irrigate plot [plot number]" x "During the [season] season, during a typical week that you irrigated, how many days per week did you irrigate plot [plot number]" x "During the [season] season, on a typical day that you irrigated plot [plot number], how many hours per day did you pump water?"

Method 1c: Product of irrigation instances and irrigation hours per instance. The survey text used is: "How many times did you irrigate plot [plot number] in [season]?" x "Each time you irrigated plot [plot number] in [season], for how many total hours did you apply water?"

These are each summed across all plots. The average of the three methods is used as the benchmark.

Details: Model benchmark for each season (2016 values only).

In each season, we estimate the following model of hours irrigated using the cross-sectional linear regression

$$\ln \text{Hours}_i = b_0 + b_1(\text{Pump Power Bin})_i + b_2 \ln(\text{Irrigated Area})_i + b_3 \ln(\text{Water Depth})_i + e_i.$$

We then calculate the estimated total hours irrigated as the exponent of the fitted values from this regression.

C Results of micro-irrigation subsidy pilot trial

The other intervention introduced in the pilot was a subsidy for adoption of micro-irrigation (MIS). This subsidy was additional to a large subsidy offered by the state government. Unfortunately, during the pilot, the government halted processing subsidy applications for several months. This meant that although some farmers expressed interest in adopting MIS, ultimately none chose to do so within the eligibility period for our additional subsidy. However, we can measure the application rates, which are likely to give a fair indication of what the adoption rates might have been under the usual government subsidy.

As shown in Table 6, the application rate of farmers offered the additional MIS subsidy was 19%. The additional subsidy was offered to all 200 farmers in Laluka village, as well as 20 randomly selected farmers in Thakar Sherdi. Of these farmers, 83 in Laluka and 15 in Thakar Sherdi had not previously used MIS and were therefore eligible for the subsidy. Out of these, 16 farmers in Laluka and 3 farmers in Thakar Sherdi submitted applications, so the overall application rate was 19%. No applications were submitted to dealers by farmers not offered the subsidy - either in Bhankhokri or by control group farmers in Thakar Sherdi.

The small sample size makes it difficult to interpret these results as treatment effects, and so rather than attempt statistical inference we simply report the raw counts and rates.

Table 6: MIS application rates in each village.

Village	Bhankhokri	Thakar Sherdi		Laluka
MIS subsidy	No Subsidy (Control)	No Subsidy (Control)	Subsidy (Treatment)	Subsidy (Treatment)
Farmers	159	348	20	200
Prior MIS adopters	71	(n/a)	5	117
No prior MIS use	88	(n/a)	15	83
Applications	0	0	3	16
Application rate	0%	0%	20%	19%

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