4-2021

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April 2021

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Funding sources
This research is partially supported by the Agriculture and Food Research Initiative (AFRI) Water for Agriculture grant no. 2017-68007-26584/project accession no. 1013079 from the USDA National Institute of Food and Agriculture and by the Nebraska Agricultural Experiment Station with funding from the Hatch Multistate Research capacity funding program (Accession Numbers NEB 1011054, NEB 227784).

Can engagement improve groundwater management?

ABSTRACT

Groundwater use often has external effects on both the environment and future groundwater benefits, leading to over withdrawal. Ostrom's research on common property resources (CPR) and related literature indicates that CPR management may improve if users have more information about the groundwater system, more opportunities for communication, and empowerment to regulate. In this paper, we conduct a computer laboratory experiment involving 180 students to evaluate the role of these components of engagement in reducing irrigation withdrawals from an aquifer. Our treatments, which consisted of different levels of information, communication and empowerment, resulted in decreases in groundwater extraction and increases in irrigation profits over nine-year extraction horizons. Enhanced information and communication also increased the fraction of subjects who voted for and complied with collective action in the form of quotas on pumping levels.

Key words: Groundwater depletion, engagement, experimental economics.
JEL: Q51, Q54, C61.

1. Introduction

Management of groundwater quantities is a social issue when externalities are involved – consequences to others not taken into account when individual users make their decisions.

Examples of externalities to the choice of quantities to extract are reduced surface water flow and related damage to ecological amenities, land surface subsidence, reduced groundwater in storage, and increased pumping costs for other users. In this paper we consider only externalities imposed on other irrigators in the context of a common property resource (CPR): an aquifer shared by several irrigators. These irrigators may not take into account the increased pumping costs they impose on others when they decide how much water to extract. The pecuniary incentives in this situation are for each irrigator to always pump the amount that maximizes their own current profits, because they will not be able to appropriate any water saved by pumping less – someone else will. This increases the amount an irrigator would extract relative to what they would extract if they took those costs into account. If there are many irrigators, annual groundwater depletion may far exceed what is desirable even for just the group of irrigators themselves.

Ostrom (1990) devoted much of her Nobel-awarded career studying how societies have and might deal with common pool resource problems such as the irrigation commons. She distilled from her research a number of characteristics that are common to institutions that have proven successful in CPR management. Babbitt, et al (2015), for example, found that stakeholders felt that the institutional structure of Nebraska's Natural Resources Districts conformed reasonably well to these characteristics.

It has been more difficult, however, to identify what processes might help to develop institutions with the characteristics Ostrom identified. Meinzen-Dick (2007) has noted that what seems to have worked in one location does not work in another. Meinzen-Dick, et al (2018) later explicitly proposed that experiments conducted in the field with stakeholders are in themselves a useful intervention that could lead to more sustainable water management institutions. In the research reported here, we develop a laboratory experiment to explore the hypotheses that engagement processes can lead to (1) more sustainable irrigation extraction decisions and (2) more likely adoption of collective action in the form of pumping quotas.

The term engagement comprises a wide range of interactions among those who are affected by a common issue, interactions arising from the stakeholders or introduced by outside interventions. When effective, engagement fosters meaningful and equitable exchange of ideas, collectively identifies new opportunities, and leads to changes in attitudes, knowledge, perceptions, and behavioral change (Sterling, et al 2017). In the experimental design of this paper, we explore how extraction behavior is affected by two components of engagement: information/communication and empowerment to regulate. According to Riches (2005) and Noland and Phillips (2010), these components correspond to three of the principles for successful commons management as identified by Ostrom (1990): information, communication and empowerment.

2. Literature[1]

There exists a large body of research in experimental economics that investigates behavior in CPRs. We review here those studies that relate to the objective and methods of this paper.

Ostrom (1990) suggests that stakeholder engagement in CPR management will be improved if participants have more information and are able to communicate about how to respond. However, it is often difficult to distinguish the contribution of communication versus

[1] We only include research most directly relevant to our study that have focused on the effect of information, communication and empowerment on management of the quantity of irrigation water as a common property resource (CPR). Babbitt, et al (2015) lists these characteristics, among others based in Ostrom (1990), required for successful local CPR management. Good reviews of the broader literature on irrigations commons can be found in Yu, et al (2016) and Edwards and Goolfoos (2020).

the information that is shared or created by the communication. We also note that information about what individual neighbors are doing may have quite a different impact on behavior than information about aggregate behavior or about hydrogeologic structure. More information about what others are doing generally increases extraction because it stimulates responses to the revealed existence of free riders (Janssen, 2013; Janssen et al, 2015), whereas hydrogeographic information may induce conservation instincts and thereby reduce extraction.

To explore the role of information on common property resource management by actual irrigators versus students, Tisdell, Ward and Capon (2004) and Ward, et al (2006) conducted experiments that were essentially identical (one with students, the second with farmers) with different levels of information. Relative to no information, one treatment provided information on aggregate extraction and an opportunity for discussion, and another added information about individuals' extractions. In the lab experiment, aggregate information significantly reduced extractions below the control treatment, but adding individuals' information did not reduce them further. In the field experiment, both aggregate information and individual information decreased extraction, but the reductions were not statistically significant.

Peth, et al (2018) developed a laboratory experiment in which farmer subjects chose crops, fertilizer levels, and distance to water while applying fertilizer. The treatments included two levels of information regarding (i) the consequences of non-compliance with a distance-to-water rule, and (ii) the consequences and information about neighbors' behavior; both versus no such information. Information treatments were applied between the 4th and 5th of eight years of play. Despite substantial variability in individuals' choices, the two information treatments significantly (at the 5% level) reduced the share of non-compliance, but there was no additional effect of adding information about neighbors' behavior. Regression analysis also failed to identify significant additional effects of the neighbors information, contrary to expectations of the authors.

To examine the effects of communication among players, Janssen and Ostrom (2008) constructed a laboratory game for an abstract checkerboard resource resembling an open access fishery. Groups of players that were not allowed any communication realized only about a fourth of maximum tokens achievable over the course of a trial, but when they were given a 10-minute discussion opportunity among 5 players between rounds, the cooperation allowed them to double the number of tokens they were able to harvest. The harvest achieved did not change when the number of discussants increased to 15 players.

Using a modification of this experiment to include different amounts of information, Janssen (2013) and Janssen et al (2015) confirmed that when subjects in groups were able to communicate between rounds they were able to cooperate and earn more tokens over the course of a trial than when communication was not allowed. But groups that had information about the status of harvesting across the entire resource were unable to earn as many tokens as those with more limited information only about harvesting in their immediate neighborhood. The authors attributed this latter outcome to unrealistic expectations about cooperation that were not corrected as quickly with limited information.

In another experiment to evaluate the role of information and communication in reducing water extraction, Cardenas, Rodriguez and Johnson (2011) structured an experiment with up-stream and down-stream irrigators for subjects extracting "units" over 20 rounds of the game. The first 10 rounds were played with no communication, while for rounds 11-20, face-to-face communication was allowed either just once before the 11^{th} round or before every round, versus continuing with no communication as the control treatment. The repeated communication treatement results in significantly less extraction (at the 1% level) over remaining rounds, while reductions due to the one-shot communication treatment were significant during rounds 11-13, but not for rounds 18-20.

Meinzen-Dick, et al (2018) conducted an experiment among villagers in Andhra Pradesh, India in 2013 and 2014, in which subjects' choice was between high-water-use crops versus low-water-use crops. Up to 10 years were played without communication to establish control behavior, during which water tables fell. This was followed by a discussion of the experience, and a second set of up to 10 rounds with face-to-face communication of up to 1 min between rounds. In a logistic regression analysis of individual choices, communication reduced the likelihood of a water-consumptive crop choice by about .305 in 2014 (significant at the .01 level), but by only a statistically insignificant .066 in 2013. The authors suggest that the higher significance of the 2014 effect might be due to learning, given that the game was repeated in the same villages (not necessarily the same subjects).

While some experimental CPR studies have empowered subjects to develop collective action, few have examined the effect of that empowerment on individual behavior. Janssen et al (2012) describes a series of experiments conducted with both villagers and university students in both Thailand and Colombia. Subjects were assigned along an up-stream, down-stream configuration. After 10 rounds of extraction, groups were empowered to vote on 3 alternative water allocation rules: equal quotas and either rotating access or randomly-assigned access. Data were pooled for analysis across all groups. Among the 32 groups, 22 selected the rotation rule, 7 the quota rule and 3 the random-access rule. Extraction levels across most positions along the stream decreased after the rules were invoked (rounds 11-20), with the quota rule and the random-access rule having the most significant effects across the positions. This provides some evidence that water management decisions can be improved when the managers are empowered to vote on collective action. The experiments by Janssen and Ostrom (2008) do provide an opportunity for ad hoc cooperation, but do not empower subjects to adopt collective action.

To our knowledge, no other laboratory experiments have explored simultaneously the contributions of information, communication and empowerment on extraction decisions on allocation of a common property resource, as we do in this study[2].

3. The Experiment

For this research, we designed and implemented a computer laboratory experiment to explore whether irrigators' pumping decisions and irrigation policy preferences are affected by engagement. The design was guided by precedents set by a number of similar experiments (Anderies et al 2013, Baggio et al (2015), Cardenas et al (2008, 2011), Janssen et al (2012), Pfaff et al (2015)). Groups of five subjects play the role of irrigators who share an aquifer that serves as a common property resource. We imposed six different treatments on the way the game was played, with each treatment replicated on six different groups, allowing us to observe 30 subjects playing under each treatment. The total number of subjects in the experiment is thus 180[3]. A bioeconomic model underlying the experiment controls the year-to-year changes in water level

[2]Appendix C includes a review of similar literature addressing water quality issues, well summarized by Jones and Vossler and by Palm-Forster, et al (2019). Communication has been found to influence non-point polluting behavior when incentives are tied to ambient environmental quality.

[3] A reviewer expresses concern that the 5 persons per group with 6 replications (30 observations per treatment) is too small for statistical 'reliability'. Our choice of numbers was guided by previous studies (Janssen and Ostrom (2008), Suter, et al (2012, 2019), Tellez Foster, et al (2017), and Meinzen-Dick, et al (2018)) and some basic power analyses indicating that 30 subjects per treatment in groups of 5 would be satisfactory. Based on results of Suter (2012), we expected that untreated, our subjects would pump an average of 22 units assuming a standard deviation of 11 (half of mean), while after treatment they would average 14 units with a standard deviation of 7. To compare treatment means (round 3 of treatments 2, 3, 5 or 6 with round 3 of treatment 1 or 4), we found that 30 subjects per treatment would provide a power of 90% with an alpha of 5%. To compare round 3 with round 2 within any given treatment (after versus before the treatment was applied), assuming a correlation of 0.01, we again found that 30 subjects per treatment would provide a power of 90% and an alpha of 5%.

and pumping costs. Each subject makes annual pumping decisions to earn tokens over a 9- or 10-year horizon (determined at random to avoid end-of-game myopic choices), in each of four rounds, with parameters being initialized at the beginning of each round. After the first two rounds[4], each group of 5 receives one of the six treatments to be in effect the last two rounds, treatments involving 3 different levels of information and communication, and 2 types of quotas to vote on (voluntary and mandatory). Players were not allowed to talk with one another, unless instructed that they could do so via a chat channel. Players received a cash payment at the end of the experiment, proportional to the token profits earned during the experiment. We then examine the effects of the treatments on pumping behavior and subsequent aquifer water levels and participant earnings, both by comparing treatment means and by examining individual choices using regression analysis (Suter, et al. 2012; Palm-Forster, Suter and Messer 2018).

Both the introduction to the game and the game itself were controlled by a computer program, with subjects at individual workstations in the same room. It was programmed and conducted using the Z-tree package of Fishbacher (2007). All sessions occurred in April, August or September 2018, on the campus of the University of Nebraska-Lincoln, in compliance with the DHHS Regulations for the Protection of Human Subjects and under the approval of the Institutional Review Board.

3.1 Bioeconomic model

[4] This structure of introducing treatments is similar to that of Janssen and Ostrom, where round 1was open-access and different treatment levels of communication were invoked for rounds 2 and 3. The same type of analysis is found in Tellez, Rapoport and Dinar (2017), Cardenas, Rodriguez and Johnson (2011) and Meinzen-Dick, et al (2018). Note that this structure allows us to examine the effect of treatments by comparing behavior in last two rounds with the first two rounds within treatments, as well as comparing behavior in the last two rounds across treatments.

To facilitate subjects' understanding of the game, we constructed a simplified farm decision and groundwater change model, similar to those used in other papers such as Feinerman and Knapp (1983) and Suter et al. (2012). Five subjects constitute a group who play the role of irrigators pumping simultaneously from a common hydrologically unconfined aquifer. Their individual pumping options and payoffs are identical: each year each one may choose to pump any discrete number of units of water, *y*, from 1 to 40, with revenue and pumping costs, respectively, determined as

$$R = \alpha y - \frac{\gamma}{2} y^2$$
$$C = \phi y d \tag{1}$$

where α, γ and ϕ are parameters, and *d* is depth to water. Our particular parameterization then specifies profit as

$$Profit = R - C = \alpha y - \frac{\gamma}{2} y^2 - \phi y d \tag{2}$$

Thus, given an initial depth to water of 100 feet, pumping 35 units maximizes current period profit, resulting in profit of 2450 tokens for that year. To avoid the need for subjects to calculate, they were provided a table showing profit for each pumping level at the beginning of each year. At the end of the session, subjects were paid cash in proportion to their accumulated profit tokens, (which averaged a payment of $23.28 per subject, including a show-up payment of $10).

We constructed characteristics for an aquifer underlying 5,000 acres of irrigated crops. If all 5 subjects simply maximized current profit, it would result in steep declines in profits over 9 to 10 years, yet the aquifer would provide sustainable incomes if all subjects restricted their pumping each year to about 14 units. In a bathtub model similar to those of Feinerman and Knapp (1983) and Suter, et al (2012), the change in depth to water each year depends upon the total pumping amount ($\sum_{i=1}^{n} y_{it}$), the recharge (r), and hydrological characteristics of the groundwater aquifer including area (A) and storativity or storage coefficient (S) which is a dimensionless quantity that measures the volume of water released per unit decline in hydraulic head in the aquifer), as

$$d_{t+1} - d_t = \left(\frac{\sum_{i=1}^{n} y_{it} - r}{AS}\right). \quad (3)$$

The coefficients and units we chose are *y* (in 100,000 ft^3), r = 6,400,000 ft^3, A = 5,000 acres, and S = .00065. For the initial year, *d* = 100, so if all 5 pumpers pump the profit-maximizing 35 units, the change in depth to water would be 30.33 ft, i.e., depth to water would increase from 100 ft to 130.33 ft, and pumping costs the subsequent year would rise from $100 per unit pumped to $130.33.

3.2 Experimental design

The bioeconomic structure of the experiment insures that if the five subjects in a group maximize income every year, both water in the aquifer and subjects' earnings will decline dramatically through the 9 or 10 years simulated in a single round of the game. It therefore reflects the over-exploitation expected in a common-property resource. The issue explored in the experiment is whether enhanced levels of information and communication (IC) cause subjects to reduce their pumping levels and whether enhanced IC causes them to be more willing to support collective action in the form of quotas that limit everyone's pumping rates.

Each of the five subjects in the group playing the game together chooses a pumping level each year for either 9 or 10 consecutive years (chosen at random by the computer), with aquifer levels and income declining. This sequence we refer to as a *round*. The group completes four such rounds, with the aquifer parameters reset to initial conditions for each round. The set of 5 interactive subjects completing four rounds we refer to as a *group* (the experiment consisted of 36 groups - 6 replications of the 6 treatments). Individual subjects (180 in total) participated in one and only one group. After the first two rounds, the weak or strong IC treatments were invoked and then subjects voted on whether to impose quotas on pumping behavior during the third and fourth rounds (voluntary in one case, mandatory in the other). Hence this is a two-factorial design, with three levels of IC (basic, weak and strong) and two kinds of quotas offered for a vote (voluntary and mandatory), for a total of 6 treatments. Each treatment was replicated with 6 groups of 5 subjects. Details of each treatment are described below, with an abbreviated tabular description in Table 1.

Student subjects were recruited using posters scattered about the University of Nebraska-Lincoln campus. Sessions were scheduled whenever a sufficient number of students was available. When the students appeared by appointment at the lab, they seated themselves at workstations and were given brief verbal instructions to accompany a handout that explained the structure of the game and their role in the game (this handout is included in the Appendix). Although no test of comprehension was conducted, the computer program guided the group though a 3-year orientation round to familiarize them with the mechanics of play . Subjects were not able to associate player numbers on their screens with workstations in the laboratory.

Subjects were guided on their monitors through a 3-year example of the experimental procedure to orient them. Following that, they began the first round. When all 5 subjects had made their pumping choice for a given year, the entire group proceeded to the next year, etc. Prior to each year's choice, the subject's own history of pumping and net revenue was presented on the screen, along with the averages for all pumpers and the depth to water.

Following the fourth round, subjects completed a brief questionnaire, and each was paid a cash payment in proportion to the number of tokens earned over the four rounds of play, plus a show-up payment of $10. Most sessions lasted about an hour and a half.

Information and communication (IC) treatments

Basic IC– Bioeconomic information in this treatment was limited to the introductory handout for all participants (see Appendix). Between each year of play, subjects were shown a summary of their own behavior and profits in previous years, the average of pumping amount by all five players in previous years, and the current level of the aquifer. There was no opportunity for communication among subjects.

Weak IC– In addition to basic IC, subjects were provided expert hydrologic information, which included the estimate that pumping 14 units per irrigator would result in a sustainable water supply. Subjects were provided an opportunity to communicate with each other for 5 minutes via a chat box before voting on whether to invoke quotas on pumping behavior during the last two rounds.

Strong IC– In addition to weak IC described above, during the final two rounds, between each year subjects were also shown information about the individual pumping choices of each of the other subjects every year, which revealed how many pumpers exceeded the quota each year. Subjects were also given the added opportunity to communicate via chat box between each year for 2 minute.

Quota policy treatments

The quota treatments represent two types of empowerment of participants to vote for or against one of two types of quotas.

Voluntary Quota- In the ***voluntary quota*** treatment, subjects voted on two options: (1) no change from the unregulated play of the first two rounds, or (2) voluntary quotas and if so at what level. If the majority vote was in favor of voluntary quotas (as was the case for all groups), the level of the quota was the average of those specified in the vote.

Mandatory Quota- In the ***mandatory quota*** treatment, the two options were: (1) no change from the unregulated play of the first two rounds, or (2) mandatory quotas and if the latter at what level. It was explained that the penalty for exceeding the quota is 1,000 tokens, but because of limited enforcement resources only one pumper could be monitored each period, selected at random from the five pumpers. Thus, in effect, there was a 20% chance of being caught and penalized if one exceeded the quota.

Table 1. Summary of the treatments, replicated six times with groups of five subjects.

IC level	Information	Communication	Type of quota offered	
			Voluntary	Mandatory
Basic	Handout; own behavior, average behavior and aquifer level each round	none	Treatment 1	Treatment 4
Weak	Add: Sustainable pumping level is 14 units	5-min chat before vote	Treatment 2	Treatment 5
Strong	Add: Pumping behavior of every player	Add: chat every year	Treatment 3	Treatment 6

Note: 5 subjects per group, decisions for either 9 or 10 years in each of 4 rounds, 6 treatments, 6 replications (groups) of each treatment.

<u>Data recorded</u>

The behavioral data collected from each subject are (a) the chosen amount of water pumped by each subject during each of the 9-10 years played, (b) the vote on whether to impose quotas and (c) whether quota was violated and if so by how much.

Data on the consequences of these choices were also collected in the form of (d) profit realized by each subject each of the 9-10 years of play, (e) the change in depth to water of the aquifer each year, (f) the profit accumulated over the 9-10 years and (g) the cumulative change in depth to water of the aquifer over the 9-10 years.

4. Results

We expect the pumping behavior of subjects to be affected by the treatments, but as a result of those individual decisions, the aquifer levels and long-term profits are also affected by the treatments, so we examine all three of these outcomes. We begin with a preliminary inspection of the data, a simple comparison of mean effects of the six treatments on pumping decisions[5]. We then proceed to regression analyses of individuals' decisions to further isolate the effects of treatments versus other factors[6].

4.1 Average treatment effects

Table 2 and Figure 1 report the effects of treatments on pumping decisions. In Table 2, for each treatment we compare average extraction decisions in rounds 1 and 2, before treatments were

[5] It is important to note that the subjects were chosen at random from the population of all students and that their assignment to groups was also random. This is important to have in mind as Abadie et al (2017) state that clustering should not be done in this case.
[6] Data without information identifying subjects and analytical programs are available upon request from the corresponding author.

applied, versus those in rounds 3 and 4 after the treatments were applied[7]. Note that rounds 1 and 2 were played under exactly the same conditions across the six treatments - basic IC with no mention of, or opportunities for, quotas.

In Figure 1 we compare the 9-year time paths of these extraction decisions in round 2 (before treatments were applied) and round 3 (after treatments were applied). In round 2 (panels on the left) all the extraction paths look similar as we should expect, but after the treatments were applied (panels on the right), the extraction trajectories were much flatter and lower, except for treatment 4.

Table 2. Averages of individual subjects' pumping decisions under each treatment (30 observations for each value: 5 subjects in each of 6 replications per treatment).

		Quota treatment	
IC	Round	Voluntary	Mandatory
		(treatment 1)	(treatment 4)
Basic	Average round 1&2	17.3	17.8
	Average round 3&4	16.6	17.8
	Difference	0.7	0.0
		(treatment 2)	(treatment 5)
Weak	Average round 1&2	17.6	17.8
	Average round 3&4	15.7	13.9
	Difference	1.9***	3.8***
		(treatment 3)	(treatment 6)
Strong	Average round 1&2	18.1	16.5
	Average round 3&4	15.1	14.8
	Difference	3.0***	1.6*

Note:. Test of difference in means was performed between the average per subject in Round 1&2 and 3&4 (observations=30 each) for each treatment using a two-sample t-test with unequal variances[8]. Significance levels are: * statistically significant at 10%, ** at 5%, *** at 1%.

[7] We made similar comparisons between just the second round versus just the third round. The results did not differ in any important way.

[8] Per reviewer request we did check for normality using the Shapiro-Wilk W test. We do not reject normality except in Treatment 2, round 1&2 and in Treatment 3, round 3&4. We also tested these means using the nonparametric sign test with the same significance results as the t-tests we report in Table 2, given observations=30. When using all observations (observations=540), rather than the averages per individual (observations=30), all significance results are the same except for treatment 6 that is significant at 1%.

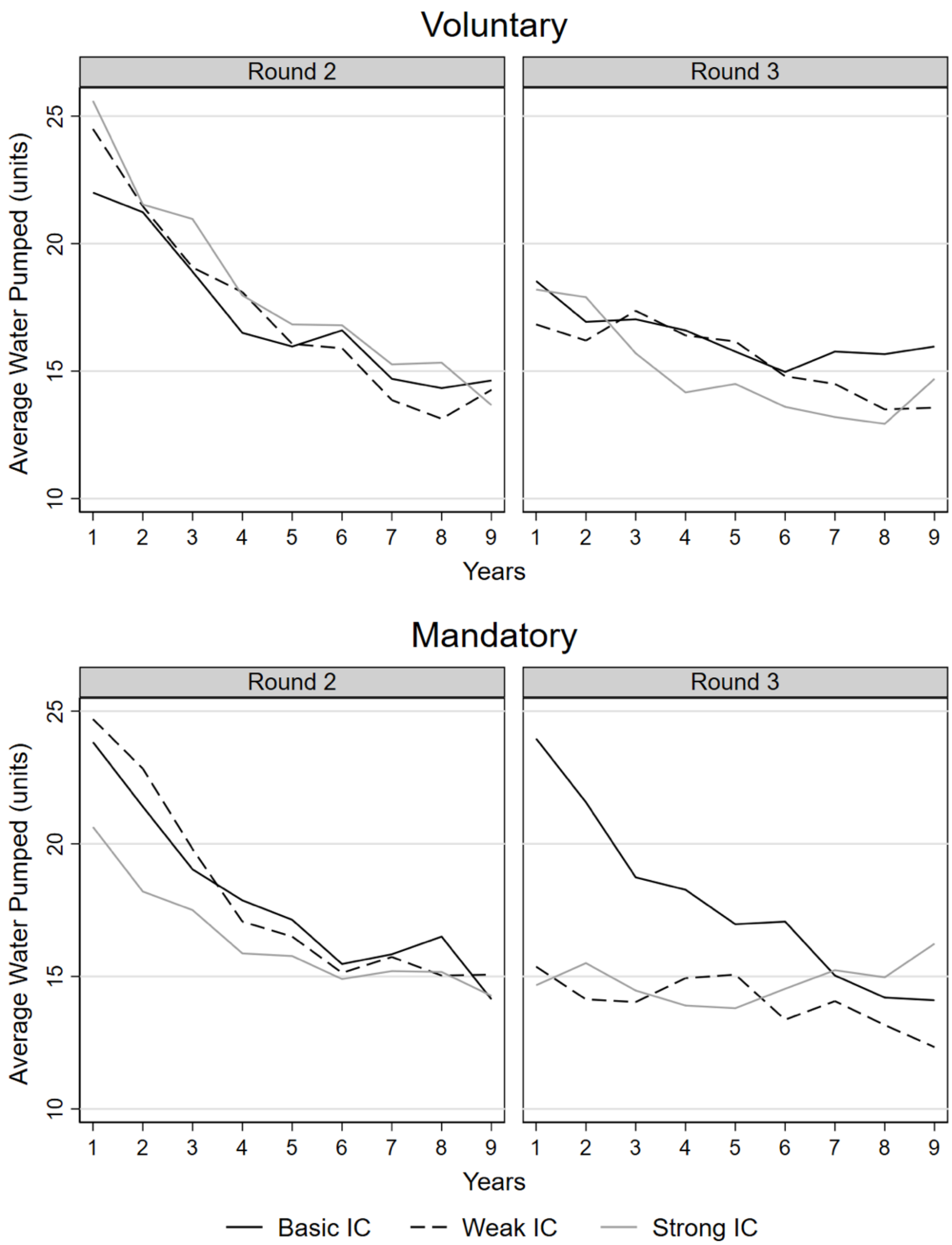


Figure 1. Average water pumped over time for the 6 treatments in Rounds 2 (pre-) and 3 (post-treatment). Only the first 9 periods are included.

IC treatment effect: One measure of treatment effects is to compare the average of rounds 3 and 4 across treatments, as these were the rounds with treatments invoked (Table 2). Under voluntary quotas, pumping under the enhanced IC levels declines with higher levels of IC, as anticipated (16.6, 15.7 and 15.1 units) but the three averages differ by less than 5%, suggesting little IC effect. Under mandatory quotas, pumping under the three IC levels (17.8, 13.9, 14.8) reveal more substantial pumping reductions under higher IC, but pumping under strong IC was greater than under weak IC.

The second measure of treatment effects (a "within treatment" measure) is to compare pumping in rounds 3 and 4 of a given treatment with that in rounds 1 and 2. By this measure both weak IC and strong IC significantly reduce pumping rates, whether in conjunction with voluntary or mandatory quotas, as is shown by Table 2. We observe an issue with respect to treatment 6, strong IC under mandatory quotas, in that the reduction in pumping is significant only at the 10% level. This insignificant reduction might be due to this treatment average being lower and closer to 14 than any other treatment in the first two rounds[9].

Nonetheless, we can reasonably conclude from the examination of average results, either across treatments or within treatments, that enhanced IC does result in reduced pumping rates.

Quota treatment effect: The effect of the quota treatments on pumping can be observed by comparing columns across Table 2. The first row (rounds 1&2, treatments 1 and 4) shows results under identical experimental conditions, so one would not expect any difference between columns. The second row (for rounds 3 & 4, treatments 1 and 4) indicates a modestly higher pumping rate under mandatory quotas but no reduction in pumping and a statistically insignificant reduction in pumping of 0.7 units under voluntary quotas. For the remaining treatments (2, 3, 5, and 6) we can examine whether the mandatory quota treatment results in a larger *reduction* in pumping than the voluntary quota treatment as expected, by comparing the difference between rounds 1&2 and rounds 3&4. These "Difference" rows indicate inconsistent

[9] We thank a reviewer for this insight.

results, with the mandatory treatment resulting in a larger reduction in pumping under the weak IC treatment, while under the basic and strong IC treatments, voluntary quotas resulted in the larger reductions. These results indicate that the offers to vote on quotas and the quotas themselves might not have any consistent effects on average pumping rates. We explore this issue further in the regression analyses discussed below.

Ultimately, the problem of the irrigation commons is over-depletion of the water resource. Figure 2 illustrates the effects of IC and quota treatments on groundwater depletion as reflected by the time paths of depth to water in the aquifer. Total depletions by the ninth year under were decreased by IC under both types of quotas. (See Table A1 in Appendix for details of final depth to water by treatment.)

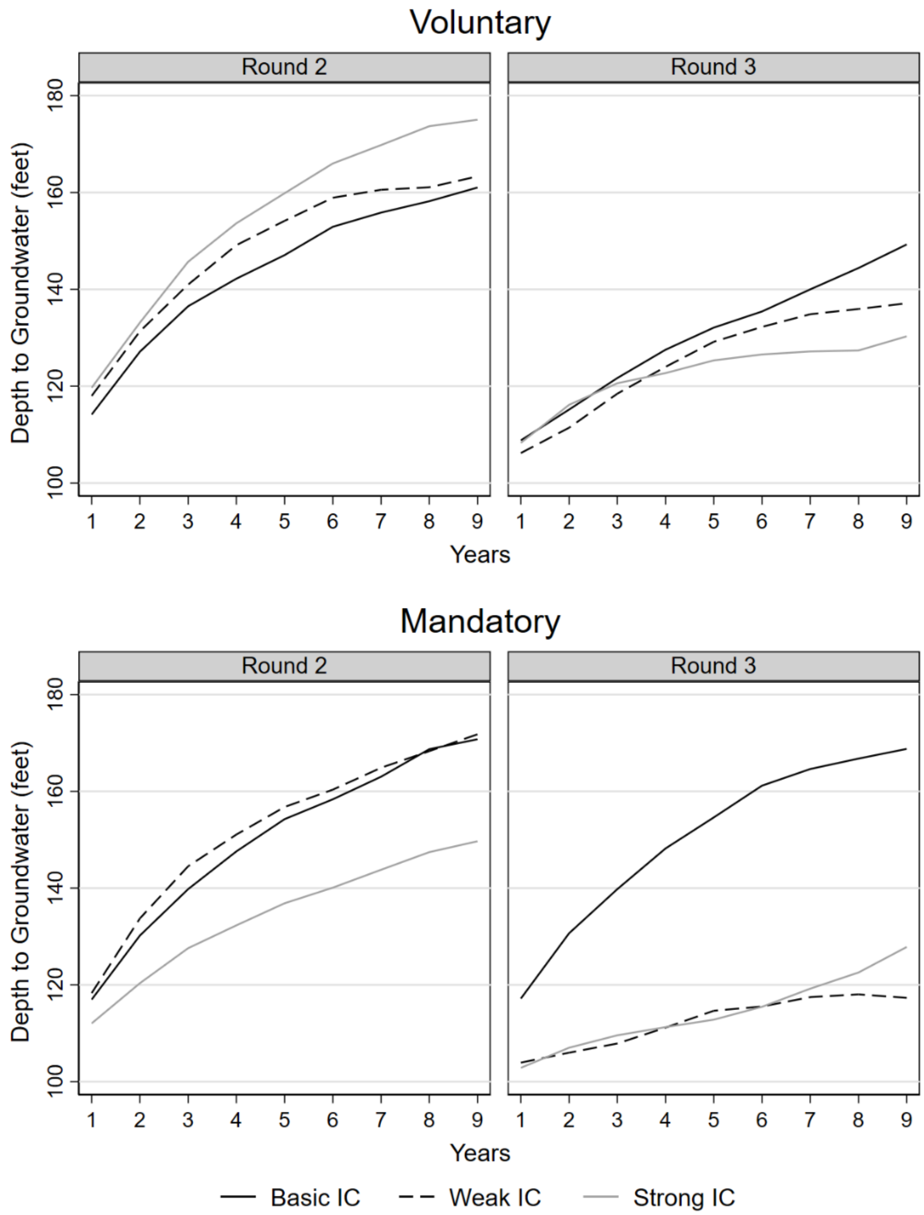


Figure 2. Average depth to water over time for the 6 treatments in Rounds 2 (pre-) and 3 (post-treatment).

The time path of groundwater extraction indirectly determines the time path of profits because of the increase in pumping costs. Figure 3 displays these time paths, pre- and post-treatment. Yearly profits fall more slowly after treatments (Round 3) and they decline most slowly under mandatory quotas.

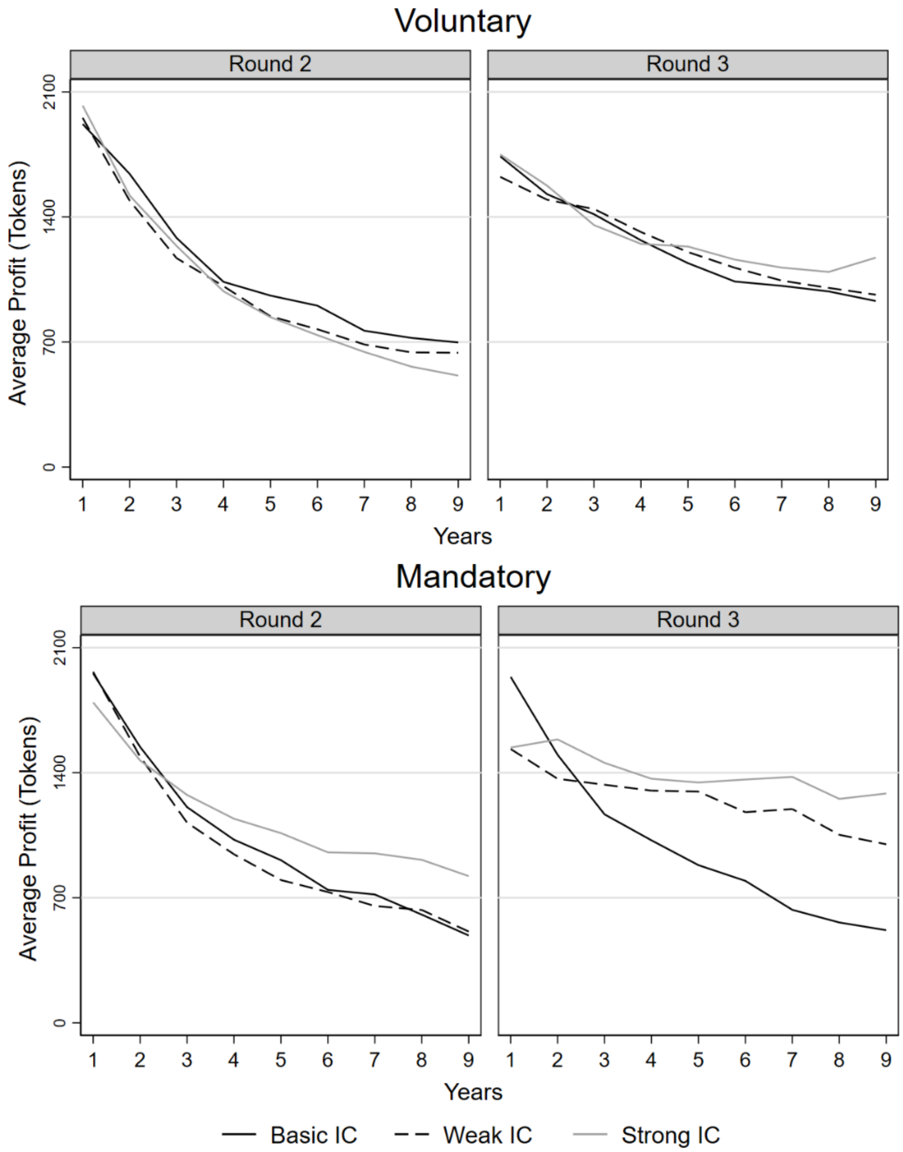


Figure 3 Average profit (tokens) over time for the 6 treatments in Rounds 2 (pre-) and 3 (post-treatment).

While the above comparisons of average results leave no doubt that enhanced IC treatments reduced annual water extractions and nine-year depletion, it is not obvious that this is in the interests of irrigators, i.e., whether it increased their own incomes. Figure 3 and Table 3 report average profits earned through the ninth year. We see that on average, both strong and weak IC increased accumulated profits relative to basic IC.

Table 3. Average accumulated profit by the 9th year.

	Voluntary Quotas			Mandatory Quotas		
	IC			IC		
Round	**Basic (1)**	**Weak (2)**	**Strong (3)**	**Basic (4)**	**Weak (5)**	**Strong (6)**
1&2:	9738	9104	9226	9283	9006	10264
3&4:	10905	11019	11680	8890	11141	12444
% change	**12.0%**	**21.0%**	**26.6%**	**-4.2%**	**23.7%**	**21.2%**

As we described earlier, in addition to choosing yearly pumping levels, subjects voted yes or no on whether to impose quotas on pumping levels for rounds 3 and 4, and later they decided whether to comply with those quotas. These are decisions related to subjects' willingness to engage in collective action in the form of agreeing to restrain their own behavior along with that of everyone else, for the benefit of everyone. Table 4 shows that enhanced IC dramatically increased the fraction of subjects who favored collective action in the form of quotas. It is notable that with weak or strong IC, a substantial majority of subjects voted for quotas after having played the first two rounds of unregulated extraction.

Table 4. Average number of votes for quotas during rounds 3 & 4, by treatment.

IC	**Quota**	
	Voluntary	**Mandatory**
Basic	**(1)** 63%	**(4)** 27%
Weak	**(2)** 90%	**(5)** 73%
Strong	**(3)** 93%	**(6)** 90%

4.2 Treatment effects on individual behavior

To examine the role of treatments on choices made by individuals, net of individual characteristics that might be affecting decisions, we use a Difference-in-Difference regression approach. We observe the same individual making 9 annual pumping choices (where a 10^{th} year randomly occurred, those decisions are ignored) in two pre-treatment and two post-treatment rounds, for a total of 36 choices. With 30 subjects for each treatment, that provides a total of 1,080 choices to be examined for each treatment. Subjects were chosen at random from the population of all students and their assignment to groups was also random. We test several hypotheses regarding the effect of treatments on these choices. The first set of hypotheses relate to the effect of treatments on groundwater extraction, on actual and accumulated profit, and on groundwater depletion. These provide the basis for answering the main question of this study: do IC, and empowerment for voting on quotas, improve groundwater management? The second set of hypotheses looks at the potential differential impact of IC treatments in voluntary versus mandatory quotas. The last set of hypotheses relate to the effect of IC on policy choices and compliance.

Did treatments affect groundwater use and profits?

First, we examine the treatment effect only for subjects with the same treatment, a within treatment analysis comparing results in rounds 3 and 4 with results in rounds 1 and 2.

Equation (4) is the regression equation we use to estimate the average treatment effects on yearly water extraction. These extraction decisions affect indirectly the profit obtained in that year, the accumulated profit by year 9, and the depth to groundwater by year 9, so we also examine the treatment effects for those outcomes. For subjects in each treatment *j*, we estimate equation (4), where $y_{j,i,t,r}$ represents a choice or an outcome (water extracted, profit, accumulated profit in period 9, depth to groundwater in period 9) associated with treatment *j*, subject *i*, in period *t* of round *r*, $E_{j,i,t,r}$ =1 if *r*=3 or 4 and 0 otherwise, and μ_i is a random effect[10] (captures individual heterogeneity and accounts for correlation across individuals):

$$y_{j,i,t,r} = \beta_0 + \beta_{3j} E_{j,i,t,r} + \mu_i + \varepsilon_{j,i,t,r} \quad j = 1, \ldots, 6 \qquad (4)$$

where i =1,…,30, t =1,…,9, and r =1,…,4. The effect of treatment *j* is identified as coefficient β_{3j}, given that this is a within treatment analysis and treatments occur between round 2 and 3.

Table 5 reports the estimates of the coefficient β_{3j} from each of 24 regressions (hypotheses) using Equation (4), the effect of the six treatments on each of four outcome variables (y)[11]. IC treatments significantly reduced the amount of water extracted. We expected that greater amounts of monitoring information and communication with strong IC would have resulted in greater reductions in extraction, but this was only the case under the voluntary quota option. Under the mandatory quota option, an examination of the records seemed to indicate that once a subject was caught cheating the subject continued to cheat in subsequent rounds. In addition, because this information was available to others in the group under strong IC, it may have induced other subjects to cheat too. This is reflected in the smaller coefficient (in absolute value) obtained in the column for Water Extracted and the row *"6. Strong"* relative to *"5.*

[10] Random effects estimator is consistent because we assume no correlation between unobserved heterogeneity and explanatory variables due to random assignment (Wooldrige, 2010).

[11] We also tested for learning effects. We estimated equation (4) for $y_{j,i,t,r}$ as water application including three dummy variables for rounds 2, 3 and 4 instead of a dummy variable ($E_{j,i,t,r}$) equal 1 for round 3 and 4. Results shows that round 2 dummy variable is not statistically significant for any of the treatments, indicating that subjects did not perform differently in round 2 compared to round 1. We conducted Wald tests for the comparison between round 3 and 4, and found that we cannot reject the null hypothesis of equality of the two dummy variables. These results indicate that we do not observe learning effect between round 1 and 2 (pre-treatment) and between rounds 3 and 4 (post-treatment).

Weak". It is somewhat notable that individuals in treatment 1 also extracted significantly more in the last two rounds as compared to the first two. Recall that voluntary quotas were adopted between rounds 3 and 4, so we interpret this as the effect of the quotas on extraction decisions in the absence of IC treatment.

As mentioned above, an individual's yearly profits are only indirectly determined by that individuals' extraction decisions, but also by others' decisions. Therefore, it is potentially useful to also use equation (4) to identify the effects of treatments on profits (columns 3 and 4 in Table 5). For individuals in treatment 1, for example, yearly profits were 125.1 tokens higher in rounds 3 and 4 than in rounds 1 and 2, in this case an impact of voluntary quotas. Both IC treatments resulted in a significant improvement in both yearly and accumulated profits. Voluntary quotas, without IC, also significantly increased accumulated profit through the nine years by 1146.6 tokens. Mandatory quotas, without IC (treatment 4) had no significant effect (recall the response to being caught cheating we described above).

The last column of Table 5 shows estimates of the treatment effects on aquifer depletion where the dependent variable is the change in depth to water by the ninth year of play. For the six replications of treatment 1, for example, groundwater level fell significantly less in rounds 3 and 4 (by 9.6 ft) compared to rounds 1 and 2. Over the nine years of play, the weak and strong IC treatments resulted in a decrease in depth to water in the range of 26 ft to 54 ft, relative to an average decrease of about 65 ft for all pre treatment rounds 1 and 2.

Table 5. Within treatment analysis (24 runs of equation (4)): estimated coefficients β_{3j} representing the difference between pre-treatment (rounds 1 and 2) and post-treatment (rounds 3 and 4) behavior.

	Water Pumped	Yearly Profit	Accumulated Profit	Depth to groundwater
Treatment	--------Equation (4)-----		------Equation (4)------	
1. Basic IC, voluntary quotas	-0.841* (-1.81)	125.1*** (-4.3)	1146.6*** (-3.75)	-9.615*** (2.236)
2. Weak IC, voluntary quotas	-1.887*** (-3.84)	220.6*** (-7.48)	1959.6*** (-7.02)	-26.12*** (2.551)
3. Strong IC, voluntary quotas	-3.272*** (-5.88)	282.1*** (-10.61)	2458.9*** (-9.06)	-43.84*** (2.834)
4. Basic IC, mandatory quotas	-0.117 (-0.23)	-32.34 (-1.15)	-376 (-1.41)	0.18 (1.412)
5. Weak IC, mandatory quotas	-3.969*** (-7.20)	265.3*** (-7.47)	2146.6*** (-6.6)	-54.26*** (4.939)
6. Strong IC, mandatory quotas	-1.555*** (-2.74)	243.3*** (-7.2)	2179.8*** (-6.24)	-22.62*** (4.514)
Observations for each regression	1080	1080	120	120

Note: * statistically significant at 10%, ** at 5%, *** at 1%; t-tests in parentheses.
The sample for the water pumped and the yearly profits regressions included, for each group, 5 subjects, 9 periods and 4 rounds; each group replicated 6 times, observations = (5x9x4x6) =1080. Random effects for subjects with slopes for round and period was used.
The sample for the accumulated profit and depth to water regressions consisted of observations of period 9 of 5 subjects over 4 rounds; each group replicated 6 times, observations = (5x4x6) = 120. Random effects for subjects with slope for round was used.

Did IC affect groundwater use and profits differently depending on type of policy choice?

We examine whether the effect of IC on water use and profits is affected by type of policy option (empowerment) presented to the subjects, that is, by voluntary versus mandatory quotas. Separately for the subset of subjects in each policy group, we estimate equation (5), where $y_{j,i,t,r}$ represents a choice or an outcome (water extracted, profit, accumulated profit, depth to groundwater) associated with treatment *j*, subject *i*, in period *t* of round *r*

$$y_{j,i,t,r} = \beta_0 + \beta_1 E_{j,i,t,r} + \sum_j^J \beta_{2j} P_{j,i,t,r} + \sum_j^J \beta_{3j} E_{j,i,t,r} P_{j,i,t,r} + \mu_i + \varepsilon_{j,i,t,r} \quad (5)$$

$j=1, 2, 3$ *or* $4, 5, 6$

where $E_{j,i,t,r}$ = 1 if r = 3 or 4 and 0 otherwise, $P_{j,i,t,r,}$ = 1 for treatments 2 and 3 and 0 otherwise in the within voluntary quota analysis, or for treatments 5 and 6 in the within mandatory quota analysis, and μ_i is a random effect for subject. We estimate equation (5) twice for each of the concepts of interest (water use, profits, accumulated profits in period 9, depth to groundwater in period 9), once for observations in the voluntary quota group and once for those within the mandatory quota group. The treatment effect is capture by the fourth term, the parameter vector $\boldsymbol{\beta_3}$.

Table 6 displays the average treatment effect within policy treatments as represented by the parameters of the interaction term, β_{3j}, with 16 hypotheses tested. Columns 2 and 3 display the IC effect (β_{32} and β_{33}) of treatments 2 and 3 with respect to the control group under voluntary quotas (treatment 1). Columns 5 and 6 display the IC effect (β_{35} and β_{36}) with respect to the control group under mandatory quotas (treatment 4). We find that weak (-1.04) and strong (-2.38) IC under voluntary quota decrease the amount of water applied compared to the control group (treatment 1). This is also true for those under mandatory quotas. In the mandatory quotas case weak IC induced a stronger decline on water use than strong IC. This is a reflection of the perverse incentives after extracting above the quota, as previously discussed and observed in Table 5.

Table 6. Average treatment effects on water pumped and profit, relative to basic IC.

Voluntary Quotas	Mandatory Quotas

	Weak IC (2)	Strong IC (3)	Weak IC (5)	Strong IC (6)	*Obs.*
Water Pumped	-1.042 (-1.45)	-2.383*** (-3.31)	-3.770*** (-4.84)	-1.375* (-1.77)	3,240
Yearly Profit	94.31** (-2.28)	163.9*** (-3.97)	286.5*** (-6.15)	268.4*** (-5.76)	3,240
Accumulated Profit	787.9* (-1.93)	1360.3*** (-3.32)	2528.3*** (-5.72)	2573.3*** (-5.82)	360
Depth to Groundwater	- 15.021*** (3.974)	-32.681*** (3.974)	-53.101*** (5.802)	-21.779*** (5.802)	360

Note: * statistically significant at 10%, ** at 5%, *** at 1%; t-test in parentheses. Columns 2 and 3 are average treatment effects compared to treatment 1 (voluntary quotas). Columns 4 and 5 are average treatment effects compared to treatment 4 (mandatory quotas).
The sample for the water pumped and the yearly profits regressions included, for each group, 5 subjects, 9 periods, 4 rounds and 3 treatments; each group replicated 6 times, observations = (5x9x4x3x6) =3240. Random effects for subjects with slopes for round and period was used.
The sample for the accumulated profit and the depth to groundwater regressions consisted of observations of period 9 of 5 subjects over 4 rounds in 3 treatments; each group replicated 6 times, observations = (5x4x3x6) = 360. Random effects for subjects with slope for round was used.

Does IC affect preference for collective action and policy compliance?

After the first two rounds of play, during which profits declined substantially over the 9 periods, subjects were given the opportunity to vote for or against a quota policy to provide a more sustainable income. In treatments 1, 2 and 3, they were given the opportunity to vote for voluntary quotas, while in treatments 4, 5, and 6 they were given the option to vote for mandatory quotas. Under the mandatory policy, quota violations would receive a 1,000-token fine, but as subjects were told, there was only a 20% probability that violators would be caught. Table 4 has already indicated that IC treatments resulted in a significantly higher fraction of subjects to vote for this form of collective action. We use the simple probit analysis in equation (6) to examine treatment effects on individual votes:

$$p_{ij} = \gamma_0 + \sum_j^J \gamma_j E_j + \varepsilon_i \qquad j\text{=1, 2, 3 or 4, 5, 6} \qquad (6)$$

where p_{ij} = 1 if subject *i* voted for the quota in treatment *j* and 0 otherwise and E_j = 1 for treatments *j* = 2 and 3 and 0 otherwise in the within voluntary quota analysis, or for treatments *j*= 5 and 6 in the within mandatory quota analysis. Equation (6) was run twice, once for observations from the voluntary quota treatments (treatments 1, 2, and 3) and once for those from the mandatory quota treatments (treatments 4, 5, and 6).

The results, in Table 7 (column 2), indicate that weak IC subjects were 27% more likely than basic IC subjects to vote for voluntary quotas, while strong IC subjects were 30% more likely to do so. For subjects given the mandatory quota option, the corresponding marginal effects increased substantially, to 47% and 63% respectively. These results support the conclusion from the treatment means in Table 4, that information and communication engendered a greater willingness to vote for collective action in the form of pumping quotas.

We also use a simple probit analysis to examine the probability that subjects would comply with or exceed the quota:

$$z_{ijrt}^1 = \omega_0 + \sum_{j=2}^J \omega_j E_j + \tau_1 D_{ijrt-1} + \tau_2 D_{jrt-1} + u_{ijrt}^1 \qquad j\text{= 2, 3 or 5, 6} \qquad (7)$$

where $z_{ijrt}^1 = 1$ if pumping level $y_{ijrt} > quota$ and $z_{ijrt}^1 = 0$ if $y_{irt} \leq quota$, E_j = 1 for treatments *j* = 2 and 3 and 0 otherwise in the within voluntary quota analysis, or for treatments *j*= 5 and 6 in the within mandatory quota analysis, D_{ijrt-1} =1 if subject *i* had exceeded the quota and was caught in the previous year and 0 otherwise, and D_{jrt-1} =1 if one in the group of 5 had been caught exceeding the quota in the previous year, 0 otherwise. The sample used to estimate Equation (7) included only observations post-treatment, rounds 3 and 4 (*r = 3* and *4*). Equation

(7) was estimated twice, once for observations given the voluntary quota option and once for those given the mandatory quota option. Variables D_{ijrt-1} and D_{jrt-1} were included only on the regression for the mandatory quota (treatments 4, 5 and 6) given that being caught and punishment apply only to the mandatory quota option. The data sets for this regression included only those subjects that had voted for quotas. Results (Table 7, column 3) reveal that whether voluntary or mandatory quotas were offered, subjects who received an IC treatment were less likely to exceed their quota than those that did not. The likelihood of complying with the quota is higher with strong IC for the two policy options (voluntary and mandatory) than with weak IC.

Equation (7) is slightly modified to account for the size of the defection using a Tobit regression analysis:

$$z_{ijrt}^2 = \omega_0 + \sum_{j=2}^{J} \omega_j E_j + \tau_1 D_{ijrt-1} + \tau_2 D_{jrt-1} + u_{ijrt}^2 \quad j = 2, 3 \text{ or } 5, 6 \qquad (8)$$

The dependent variable (z_{ijrt}^2) is calculated in similar manner to z_{ijrt}^1 but rather than being a dummy variable it indicates the size of the defection ($z_{ijrt}^2 = (y_{ijrt} - quota)$ if $y_{ijrt} \geq quota$, $z_{ijrt}^2 = 0$ otherwise). As in the previous analyses, this equation was estimated twice, once for subjects offered voluntary quotas and once for subjects offered mandatory quotas. Table 7, last column, shows that those offered voluntary quotas who later exceeded that quota did it by a smaller amount if they had received either IC treatment. However, mandatory quotas seem to have engendered a perverse effect, in that non-compliant individuals who had received IC treatments pumped a significantly greater excess over quota than the non-compliants who had not participated in any IC. This is consistent with the observation that once non-compliance in a group was observed, other subjects would then also extract above their quota. Results in the next-to-last row of Table 7 also indicate that subjects who were caught exceeding their quota in one year were 42% more likely to exceed it again in the next year and to exceed it by a significantly larger amount than those who had not been caught in the previous year. Possibly they thought that the probability of getting caught two years in a row was small (it didn't change), or possibly they calculated that if they were going to get caught again, they might as well get caught for a large violation as for a small one since the penalty would be the same.

Table 7. Marginal effects for policy decision (eq. 6), for compliance with the policy (eq. 7) and for size of compliance (eq. 8).

	Policy Decision (voted for quota)	**Non-compliance (exceeded quota)**	**Size of Defection**
Voluntary Quota Option Treatment			
T2: weak IC, voluntary quotas	0.2666*** (0.0714)	-0.0735 (0.1818)	-4.4363 (6.5522)
T3: strong IC, voluntary quotas	0.3000*** (0.0700)	-0.2075 (0.1596)	-9.8085 (6.4821)
Observations	90	1,332	1,332
Mandatory Quota Option Treatment			
T5: weak IC, mandatory quotas	0.4667*** (0.1314)	-0.6237*** (0.1102)	-24.6496*** (6.1807)
T6: strong IC, mandatory quotas	0.6333*** (0.1019)	-0.6781*** (0.0988)	-29.7399*** (5.0914)
Subject was caught exceeding quota in previous year?	-	0.4209*** (0.1579)	15.6505*** (6.0160)
Someone was caught exceeding quota in previous year?	-	-0.0494 (0.0420)	-0.4001 (3.9582)
Observations	90	1,026	1,026

Note: * statistically significant at 10%, ** at 5%, *** at 1%; robust standard errors in parentheses. The sample for the policy decision regression included, for each group, 5 subjects in 3 treatments; each group replicated 6 times, observations = (5x3x6) =90. Probit clustering by group.The sample for the compliance and size of defection regressions included, 5 subjects in groups with majority voting for quota, 9 periods, 2 post-treatment rounds and 3 treatments; each group replicated 6 times. Marginal effects from the Probit for the noncompliance regression and from the Tobit for the size of defection regression, clustering by groups. The last two rows only observed under mandatory quota.

5. Summary and conclusions

The overall objective of this research was to examine, in a laboratory experiment, the potential effect of information and communication (IC) and empowerment for voting on quotas on the behavior of irrigators who share an aquifer as a common property resource. Given the bioeconomic structure created for this experiment, if subjects simply maximized current profit every year, the aquifer and irrigators' profits would decline dramatically over time, reflecting the fundamental problem of a common property resource. Hence the issue we examine is whether information, communication and empowerment can persuade irrigators to reduce their extractions below the rate that would maximize current profit.

We imposed treatments between the second and third of four 9-10-year rounds that each subject played, then compared the behavior before and after. The IC factor levels consisted of IC at basic, weak and strong levels. To the basic IC initially provided to all subjects, the weak IC treatment consisted of providing subjects with some quantitative hydrological information (expert opinion about sustainable extraction rates) and an opportunity for communication (one 5-minute chat opportunity). To this, the strong IC treatment added more information, specifically the amount pumped by each member of the group, every year, and more communication (chat opportunities every year). The other experimental factor consisted of two treatments, an opportunity to vote on whether to impose voluntary quotas or an opportunity to vote on mandatory quotas for the final two rounds.

We found strong evidence from these laboratory experiments that IC and empowerment can reduce pumping rates. Across IC treatments, average annual pumping rates fell significantly after receiving the treatment. This is similar to the Meinzen-Dick, et al (2018) finding that communication significantly decreased water consumption in at least one of the three years in which they conducted their experiment among villagers in India. The results are also consistent with the findings in Ward, et al (2006) that imply significantly lower extraction rates due to treatments with more information and discussion. In our experiment, the reductions in pumping improved long-run aquifer management: profits over the 9-year period were augmented. The consequences to the aquifer of the pumping reductions we observed were to reduce average total 9-year change in depth to water.

We also found that enhanced IC treatments resulted in subjects significantly more inclined toward collective action in the form of pumping quotas. These results resemble those of Cardenas, Rodriguez and Johnson (2011) who found that information treatments increased contributions for the public good (while penalties did not), and those of Peth, et al (2018) who found that increased information resulted in increased compliance with water restrictions. We conclude from our study that IC can increase subjects' willingness to support collective action in the form of pumping quotas, and reduce their tendency to cheat on those obligations.

A second factor considered in the design of the experiment was an opportunity to vote for collective action in the form of whether to impose pumping quotas during the last two rounds of play. One treatment offered the opportunity to vote on voluntary quotas and if so at what level, while the second offered a similar opportunity to vote on imperfectly-enforced mandatory quotas. Enhanced IC increased the percentage of subjects who voted for quotas and decreased the probability of exceeding it.

The experiment revealed that even without any engagement, subjects pumped less water than the amount that would maximize their current profit (17.5 units on average as compared to the 35 units that would have maximized profits the first year). This behavior reflects a kind of conservation or public good orientation on the part of some participants, perhaps not clearly calculated in subjects' minds. It confirms what other experimenters have noted (Meinzen-Dick, et al 2018; Cardenas, Rodriguez and Johnson (2011), that a majority of subjects choose to forego current maximum earnings.

What is the significance of these results? We designed an experiment that lasts less than two hours, which can only be a pale representation of information and communication that might occur over several years among groups of actual irrigators. For one thing, our experiments were constructed such that players were anonymous, whereas actual irrigators would generally know one another and their behavior might be affected by the prospect of living in the community for years to come. But our results nonetheless demonstrate that the level of information, communication, and empowerment to regulate are important determinants of the potential for effective groundwater management. Whether students' choices reflect those of real-world irrigation stakeholders is a question explored by several studies that made direct comparisons using experiments conducted with subjects from both populations. Ward, et al (2006) comment on "the seemingly similar behavior of villagers and students", while Janssen, et al (2012) report "A remarkable finding in our analysis is the seemingly similar behavior of villagers and students". On the other hand, Salcedo and Gutierrez (2014), report that students "seem to be more selfish in a game than non-students". Our outcomes do not assure us that real-world irrigators experiencing information, communication and empowerment to regulate over a number of years would respond as our student subjects did, but we believe they are suggestive of how those actual irrigators might respond to different levels of engagement.

REFERENCES

Abadie, A, S Athey, G Imbens, and J Wooldrige (2017). When should you adjust standard errors for clustering? MIT Working Paper, October 2017.

Babbitt, C, M Burbach and L Pennisi (2015). A mixed-methods approach to assessing success in transitioning water management institutions: a case study of the Platte River Basin, Nebraska. *Ecology and Society,* 20(1), 54.

Cardenas, JC, LA Rodriguez and N Johnson (2011). Collective action for watershed management: field experiments in Colombia and Kenya. *Environment and Development Economics,* 16(3), 275-303.

Croson, R and N Treich(2014). Behavioral environmental economics: promises and challenges. *Environmental and Resource Economics,* 58(3), 335-351.

Edwards, EC and T Guilfoos (2020). The economics of groundwater governance institutions across the globe. Forthcoming, *Applied Economic Perspectives and Policy,* doi:10.1002/aepp.13088

Feinerman, E and K Knapp (1983). Benefits from groundwater management: Magnitude, sensitivity and distribution. *American Journal of Agricultural Economics,* 65(4), 703-710.

Fischbacher, U (2007). z-Tree: Zurich toolbox for ready-made economic experiments**.** *Experimental Economics* 10, 171–178.

Guilfoos, T., MH, S Trandafir and E Uchida (2019). Social learning and communication with threshold uncertainty. *Resource and Energy Economics*, 55(C), 81-101. doi: 10.1016/j.reseneeco.2018.11.003 Available at: http://dx.doi.org/10.1016/j.reseneeco.2018.11.003

Janssen, M (2013) The role of information in governing the commons: Experimental results. *Ecology and Society,* 18(4), 4.

Janssen, M, JM Anderies, I Pérez and DJYu (2015). The effect of information in a behavioral irrigation experiment. *Water Resources and Economics,* 12, 14-26.

Janssen, MA, F Bousquet, J-C Cardenas, D Castillo and K Worrapimphong (2012). Field experiments on irrigation dilemmas. *Agricultural Systems* 109, 65-75.

Janssen, MA and E Ostrom (2008). TURFs in the Lab: Institutional innovations and real-time dynamic spatial commons. *Rationality and Society,* 20(4), 371–397.

Jones, LR and CA Vossler (2014). Experimental tests of water quality trading markets. *Journal of Environmental Economics and Management,* 68, 449-462.

Kuhfuss, L, R Préget, S Thoyer, N Hanley, P Le Coent and M Désolé (2016). Nudges, social norms, and permanence in agri-environmental schemes. *Land Economics,* 92(4), 641-655.

Leeuwis, C, KJ Cieslik, MNC Aarts, ARPJ Dewulf, F Ludwig, SE Werners, PC Struik (2018). Reflections on the potential of virtual citizen science platforms to address collective action challenges: Lessons and implications for future research. *NJAS - Wageningen Journal of Life Sciences,* 86-87, 146-157.

Meinzen-Dick, R (2007). Beyond panaceas in water institutions. *PNAS* 104(39), 15200-15205.

Meinzen-Dick, R, M Janssen, S Kandikuppa, R Chaturvedi, K Rao and S Theis (2018). Playing games to save water: Collective action games for groundwater management in Andhra Pradesh, India. *World Development,* 107, 40-53.

Miao, H, JR Fooks, T Guilfoos, KD Messer, SM Pradhanang, JF Suter, S Trandafir and E Uchida (2016). The impact of information on behavior under an ambient based policy for regulating nonpoint source pollution. *Water Resources Research,* 52, 3294–3308, doi:10.1002/2015WR018142.

Mukhtarov, F, C Dieperink and P Driessen (2018). The influence of information and communication technologies on public participation in urban water governance: A review of place-based research. *Environmental Science and Policy,* 89, 430-438.

Noland, J and R Phillips (2010). Stakeholder engagement, discourse ethics and strategic Management. *International Journal of Management Reviews,* 12(1), 39-49.

Ostrom, E (1990). *Governing the Commons. The Evolution for Institutions of Collective Action*. Cambridge University Press.

Palm-Forster, L, J Suter and K Messer (2019). Experimental evidence in policy approaches that link agricultural subsidies to water quality outcomes. *American Journal of Agricultural Economics,* 100(1), 109-133.

Peth, D, O Mußhoff, K Funke and N Hirschauer (2018). Nudging farmers to comply with water protection rules–experimental evidence from Germany. *Ecological Economics,* 152 310-321.

Riches, P (editor) (2005). *Effective Engagement: building relationships with community and other stakeholders Book 1 an introduction to engagement*. Department of Sustainability and Environment, State of Victoria, Australia.

Salcedo, R and MÁ Gutiérrez (2014). Cooperation makes it happen? A groundwater economic artefactual experiment. *Working Paper Series WP63*, Latin American and Caribbean Environmental Economics Program. Accessed at www.laceep.org.

Sterling, E, E Betley, A Sigouin, A Gomez, A Toomey, G C, C Malone, A Pekor, F Arengo, M Blair, C Filardi, K Landrigan and AL Porzecanski (2017). Assessing the evidence for stakeholder engagement in biodiversity conservation. *Biological Conservation,* 209, 159-171.

Suter, J, J Duke, K Messer and H Michael (2012). Behavior in a spatially explicit groundwater resource: Evidence from the Lab. *American Journal of Agricultural Economics,* 94(5), 1094–1112; doi: 10.1093/ajae/aas058.

Suter, J, S Collie, K Messer, J Duke and H Michael (2019). Common Pool Resource Management at the Extensive and Intensive Margins: Experimental Evidence. *Environmental and Resource Economics*, 73, 973–993; https://doi.org/10.1007/s10640-018-0283-3.

Tellez Foster, E, A Rapoport and A Dinar. (2017). Groundwater and electricity consumption under alternative subsidies: Evidence from laboratory experiments. *Journal of Behavioral and Experimental Economics,* 68, 41-52.

Tisdell, J, J Ward and T Capon (2004). Impact of communication and information on a complex heterogeneous closed water catchment environment. *Water Resources Research,* 40, W09S03, doi:10.1029/2003WR002868.

Ward, J, J Tisdell, A Straton and T Capon (2006). An empirical comparison of behavioural responses from field and laboratory trials to institutions to manage water as a common pool resource. Paper presented at the Eleventh Biennial Conference of the International Association for the Study of Common Property: Survival of the commons, mounting challenges and new realities. Ubud, Bali, June19th -23rd 2006.

Wooldrige, J (2010). *Econometric Analysis of Cross Section and Panel Data* (2nd edition). Cambridge, MA: MIT Press.

Yu, HH, M Edmunds, A Lora-Wainwright, D Thomas (2016). Governance of the irrigation commons under integrated water resources management – A comparative study in contemporary rural China. *Environmental Science and Policy,* 55, 65-74

APPENDIX A.

Table A1. Nine year depletion of groundwater level.

IC	Round	Voluntary	Mandatory
		(treatment 1)	(treatment 4)
Basic	Average 1&2	61.8	68.7
	Average 3&4	52.2	69.2
	Difference	-9.61	0.46
Weak		(treatment 2)	(treatment 5)
	Average 1&2	66.3	68.9
	Average 3&4	40.6	15.8
	Difference	-25.69	-53.10
Strong		(treatment 3)	(treatment 6)
	Average 1&2	73.4	51.1
	Average 3&4	31.7	28.8
	Difference	-41.74	-22.23

Appendix B.

HANDOUT: EXPERIMENT WITH RESOURCE MANAGEMENT

General Instructions:

- Switch off your cell phones.
- Do not write on the instructions. You have a scratch paper.
- Do not look at other participants' screens.
- Do not talk to other participants unless you are told to do so by a monitor.
- If you have questions raise your hand and wait for the monitor to come to you and answer your questions in private.
- You will earn cash that will be paid to you privately at the end of the session.

  a) You will earn $10 for completing the session (a participation fee).

  b) You will earn additional money, up to $20, **depending on amount of tokens you accumulate from the decisions that you and other players make.**

  c) The exchange rate for cash payments at the end of the session is

  370 tokens = $1.00

- Your understanding of the experiment will affect how much you will be paid.

Experiment Instructions:

- This experiment is a study of individual decision-making and the management of groundwater aquifer. You will play the role of a farm manager who generates profit by pumping groundwater over several successive years. In each year, you will choose how much water to pump.
- Your token earnings each year are calculated as

  Profit = Revenue - Cost

- Revenue increases with the amount of water applied, but at a decreasing rate. Your cost increases (linearly) with the depth to groundwater (because you must pump from further down, the cost per unit pumped increases).

There are 5 identical farms participating in your group, all pumping from the same groundwater aquifer. They have the same: land size, soil characteristics, and equipment to pump water. Figure 1 illustrates the situation.

- The pumping behavior of all 5 farmers in your group affects depth to groundwater for you in the future.

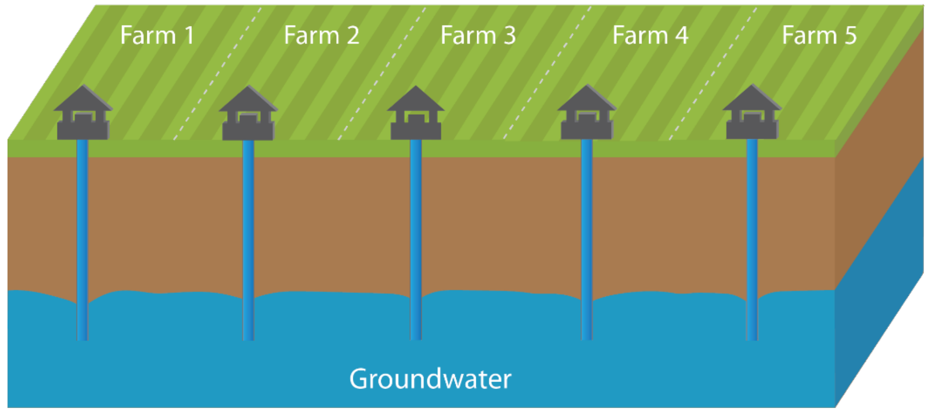
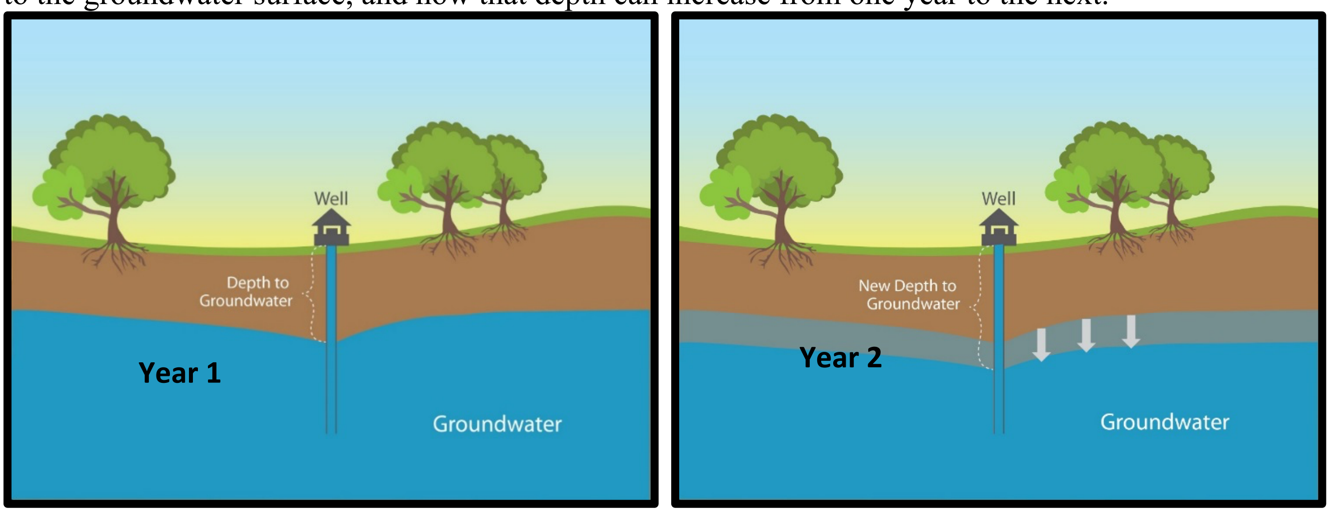


Figure 1. Example of the spatial distribution of the 5 farms in your group.

Figure 2. Illustration of "**depth to groundwater**", the distance from the land surface to the groundwater surface, and how that depth can increase from one year to the next.



After pumping in year *t,* you and your group of farmers will face a greater depth to groundwater in the following year (*t+1*), if the total amount pumped exceeds recharge from rainfall.

A greater "**depth to groundwater**" means: It is more expensive to pump water – **you lose profits**.

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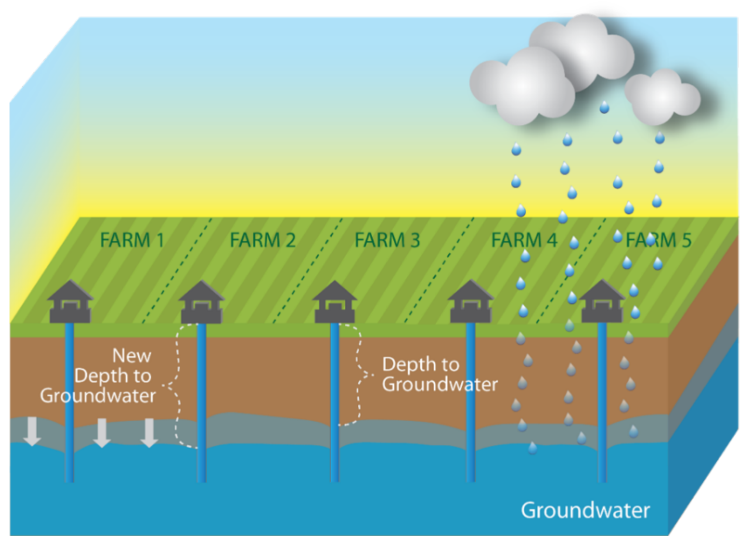

Figure 3. Example of the change on depth to groundwater from year *t* to year *t+1* due to the pumping behavior of the group of farmers.

Information on how your session will proceed:
At the beginning of the session, you will play an orientation round of 3 years that will not be included in your earnings at the end of the experiment. The orientation round will be followed by four more rounds.
The orientation round is meant to teach you how to navigate the experiment. It proceeds as follows.
On the screen for each decision year, you will see:

- a timer (in seconds) at the top right. Please read the instructions and make your decision within that time.
- a table that contains your pumping options and the profit generated by each possibility.
- the current depth to groundwater,
- a box to enter your pumping choice for the current year.
- a "Continue" button

On the next screen you will see:

- the amount of water you pumped each year to date\
- the amount of profit for each year and accumulated profit to date
- a report on depth to groundwater for each year

After playing these 3 orientation years, you will begin the actual experiment, consisting of four rounds each of which follows the same procedures as the orientation round above. Each round starts anew – they do not continue from the previous round. From here on, your decisions will affect your earnings at the end of the experiment. The number of years within each round will be determined randomly – you will not know until you are told that the round has ended.

After the experiment (when the session is over):

- You will answer a brief survey that will appear on the computer screen. The information provided by you in this survey is confidential and it will not be shared with others.
- Your answers to these questions will not affect your earnings in the experiment.
- After the survey, you will see a statement of your earnings in the experiment.
- The monitor will call your name to pay you privately, for which you will be asked to sign a receipt.

Please do not communicate with other players in the experiment unless you are told by one of the monitors.

Appendix C. Literature addressing experiments with water quality

We include references to studies that address water quality issues, as well as water allocation issues. Policies to be considered that address agricultural non-point source water quality have been of two types: payments or tradeable credits for simply *adopting* best management practices (BMPs), and payments that are based at least in part on performance measured by ambient water quality improvement.

Jones and Vossler (2014) report a laboratory experiment examining the effect of different structural features of a water quality trading (WQT) market, and provide a review of other laboratory WQT studies. None of these studies examine the role of IC on the behavior of subjects.

Palm-Forster, et al (2019) review experimental studies of ambient-based incentives for improving water quality, and present results of their own laboratory study of the effect of ambient-based subsidy reduction schemes on the adoption of a conservation technology. Neither this study nor those reviewed consider the role of IC on the behavior of subjects.

A recently published experiment by Guilfoos, et al (2019) addresses the role of communication in an experiment in which players' "production" decisions increase the probability that damage to everyone will be triggered. A communication treatment is introduced in the form of a 3-minute "cheap talk" session where participants can discuss the situation and opportunities for coordination. Cheap talk is shown to improve the payoffs to players. The paper has a good discussion of the larger game theory and experimental literature related to coordination in cases of public goods/bads. The authors suggest that the findings may be appropriate to non-point-source pollution problems as observed in agriculture.

Leeuwis, et al (2018) and Mukhtarov, et al (2018) analyze case studies of water quality programs, discussing the role of digital-platform-type IC technologies, and conclude only that they appear to solve some problems in administering such programs. They note that if IC technologies are not "participatory", they may be useful for educating citizens, but not for achieving collective action as envisioned by Ostrom.