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Permalink

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Journal

Journal of Behavioral and Experimental Economics, 68(C)

ISSN

2214-8043

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Publication Date

2017-06-01

DOI

10.1016/j.socec.2017.03.003

Peer reviewed

Groundwater and electricity consumption under alternative subsidies: Evidence from laboratory experiments

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ARTICLE INFO

Article history:

Received 11 October 2016

Revised 6 February 2017

Accepted 14 March 2017

Available online 27 March 2017

JEL classification:

Q5

Q2

Q25

C9

C92

Keywords:

Groundwater

Experimental economics

Energy subsidies

ABSTRACT

Pervasive energy subsidies for groundwater pumping pose a challenge to policy makers around the world, who have to cope with lower water tables due to increased reliance on groundwater resources for irrigation. The present paper outlines a laboratory experiment aimed to study the groundwater extraction decisions of stakeholders under alternative subsidy structures. We propose a model and a methodology for testing the implications of the model and the modifications of energy subsidies for irrigation. We analyze the performance of two traditional policy interventions—elimination and reduction of subsidy—and then analyze a novel policy: decoupling the subsidy from the electricity rate by replacing it with a lump sum transfer. Our results suggest that the rate of water extraction and the level of water in the aquifer may significantly be improved by altering the subsidy structure. An important finding for policy makers is that the decoupling leads to outcomes similar to those of eliminating the subsidy, however, with fewer political economy conflicts.

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1. Introduction

Common pool resource (CPR) dilemmas have been studied extensively in the environmental, biological, and social sciences. In his influential paper, Hardin (1968) has argued that the only possible outcome for selfish individuals who attempt to maximize their expected utility is the collapse of the commons. Traditionally, the two major solutions aimed to address his dire conclusion have been the assignment of property rights and the imposition of government regulations (Ostrom, 1990).

As a well-known and extensively studied example of a CPR, groundwater is subject to these two solutions. Our study ignores the issue of property rights as groundwater is extracted from an aquifer, which is common property. Consequently, our focus is exclusively on governmental regulations, in particular subsidies for electricity. Governments and policy makers around the world have been attempting to address overexploitation of aquifers while simultaneously guaranteeing quality supply of this resource. Too often they have not been very successful. Several misguided or poorly designed policies, that have been implemented mostly in

third-world countries, have exacerbated the tragic outcome prophesized by Hardin (1968) by providing incentives that cause users to increase their extraction of groundwater. This has been the case of subsidies for energy used to pump groundwater; the artificially reduced cost of pumping water has fostered the overexploitation of aquifers and exacerbated the negative externality generated by their users.

Reforms in the water and energy sectors often are economically costly and difficult to implement politically. Generating methods of testing reforms in a reliable and replicable way helps providing insights into the potential results of their implementation. Experimental economics provides procedures for analyzing these policy and institutional changes in a cost-effective way (Murphy et al., 2000).

The purpose of the present paper is to study the impact of eliminating, reducing, and decoupling the subsidy for electricity from the electricity price on the demand for groundwater and the CPR dilemma that it creates. For this purpose, the paper first presents a model for groundwater extraction by a small group of users of the same aquifer and then derives testable hypotheses on the basis of extensive simulations of the model reported by Tellez Foster et al. (2016a). These hypotheses are subsequently tested in a controlled laboratory experiment, where the participants are paid

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in cash at the end of the experimental session contingent on their performance. Policy implications based on the outcomes of the experiments are then briefly proposed in the conclusion of the paper.

Our approach calls for implementing a CPR dilemma game in the laboratory, where the participants make a series of intertemporal production decisions (the amount of water pumped for agricultural production) and subsequently receive monetary payoff contingent on the water table level. The pumping costs are negatively related to the height of the water table so that the more water is pumped, the deeper the water table becomes, and the more electricity is required for pumping, thereby increasing the pumping costs.¹ The water table level lags for one period so that the players face an intertemporal optimization problem.

Our experiment is similar to the one introduced by Fischer et al. (2004), who used a growth model to simulate the rate of regeneration of the resource. Fischer et al. (2004) include four generations of three subjects each. However, our experiment differs from theirs because it includes the same subjects in all the periods, and the resource stock in period t depends on the stock level in period $t-1$. The model used to predict the subjects' strategies is similar to the one proposed by Salcedo et al. (2013), who introduce a dynamic optimization model that sums the present value of net benefits over several periods of time, and where the equation of motion describes the height of the water table that depends on the collective action of the users and the height of the water table in the previous period. Suter et al. (2012) also have proposed a dynamic model that includes spatial relations based on the position of the wells and their implications for the exploitation of groundwater. They include physical and geological relations to ensure that the model is as realistic as possible. In contrast, our study accounts for the changes in behavior when the users draw water from a common aquifer and face various increases in the price for electricity, which are compensated by a monetary transfer or a subsidy of another kind.

The paper is organized as follows. Section 2 provides a brief review of experiments on groundwater extraction that are most directly related to our study. Section 3 presents a model for groundwater extraction in discrete time in which the electricity for pumping water is subsidized. Section 4 reports the theoretical implications of three alternative policies that are proposed for subsidizing electricity: the elimination, reduction, and decoupling of the subsidy from the price of electricity. The hypotheses derived from the analysis in Section 4 are then tested experimentally in Section 5 that reports a between-subject design that includes five different conditions, and Section 6 reports the experimental results. Econometric analysis of the effectiveness of the policy interventions is presented in Section 7. Section 8 concludes with a comparison of the predictions and the experimental results, followed by a brief discussion of the policy implications of our study.

2. Literature review

A substantial body of literature explores CPR problems from the experimental economic perspective. This is because changes in the management of such resources in the field are costly, slow, often irreversible, and in many cases intractable. Therefore, experimental economics provides policy makers with sound and replicable evidence that might give rise to changes in policy toward more effective management of such resources.

Fischer et al. (2004) have asked four generations of subjects to extract water from a CPR with a known recharge rate. They

concluded that their subjects generally expected other participants to extract less, and that there was always a temptation to free ride. On the other hand, Suter et al. (2012) have explored the relationship between the decisions made by stakeholders on the amount of groundwater extracted when the physical characteristics of an aquifer are taken into consideration. They reported that when farmers realize that the effects of exploiting the aquifer (social costs) exceed their own private costs (due to the cone of depression created by pumping), they tend to approach the optimal extraction rate. Ward et al. (2006) compared results from the laboratory and the field in a groundwater extraction experiment and reported that the results were comparable in both cases. Their study is relevant to our research because it compares the effects of policy manipulations with subjects in the lab and stakeholders in the field. Botelho et al. (2014) analyzed the effect of time and uncertainty in CPR dilemmas, reporting that across all treatments CPR users make decisions that lead to the depletion of the resource (or terminate the game immediately). In a previous study, Botelho et al. (2012) examined how property rights and the provision of public goods affect the depletion rate of CPR, finding that appropriation and the option of contributing to the preservation of the common resource are substitutable actions for reducing the rate of destruction of the CPR, and may explain the emergence of tacit cooperation in the common resource dilemma.

Murphy et al. (2000) conducted a series of experiments with highly sophisticated software that calculated in real time the equilibrium prices and allocations for trade in water rights. These experiments were designed to test the mechanism of "smart" water markets that could achieve efficiency and the highest benefits from trading using modern technology. Their conclusions are that the design of water markets with the aid of technology might help achieving efficiency at a reasonable cost.

These studies have not explored the effects on subjects' behavior when subsidies for extraction are modified in a CPR dilemma context. Our proposed experiment is designed to study how agents make extraction decisions based on the level of subsidy to electricity for pumping groundwater. This implies that the cost of extracting groundwater varies not only according to the water table but also according to the subsidy mechanism.

3. A model for groundwater extraction

The model considered in this section builds on the model of Provencher and Burt (1993), and the functional form of the profit function builds on that of Salcedo et al. (2013). Section 3 only presents a summary of the model. For a complete derivation of the results, see Tellez Foster et al. (2016a).

The aquifer considered here is boxed-shaped, and the pumping cost function is linear in the height of the water table as the state variable. The farmers (players) are assumed to be homogenous with a single crop and same-sized farm. The benefit function for pumping groundwater for farmer j at period t is given by

$$B_{jt} = \delta u_{jt} - u_{jt} \left[\frac{\gamma P_E \xi}{(\bar{X} - x_t) AS} \right] - C_0, \quad (1)$$

where δ is the constant marginal product of water extracted by farmer j at period t that is denoted by u_{jt} ; γ is the subsidy to electricity for pumping groundwater; P_E is the price for electricity; and ξ is the amount of electricity required to pump one cubic meter of water to a height of one meter. As mentioned earlier, the cost function is linear in the height of the water table following the modification to Provencher and Burt (1993) made by Salcedo et al. (2013). In our model, $\bar{X}$ is the maximum height of the aquifer; x_t is the height to water table at period t ; A is the area of the aquifer; S is the storativity; and AS is the volume of the aquifer available

¹ Since we are only interested in the amount of revenue from irrigation water, the payoff does not depend on the production level. Extensions of the model could include production level, type of crop, and price of crops as alternate determinants of water consumption.

for storing water. C_0 is the fixed cost of pumping; it is generally associated with installing and maintaining pumping equipment.

The equation that relates users' behavior at period t with the pumping conditions in the next period is given by

$$x_{t+1} = x_t + \frac{\sum_{j=1}^N u_{jt} - R}{AS}, \quad (2)$$

where the height of the water table in period x_{t+1} is equal to the current height plus the amount of water pumped in the current period $\sum_{j=1}^N u_{jt}$ and minus the recharge rate R , all divided by the volume of the aquifer AS .

The model maximizes the present value of net benefits (profits) over an infinite-period horizon. Two types of users are considered separately: myopic and strategic. *Strategic* users are far-sighted and therefore consider the implications of their present extraction decisions on the groundwater level and, consequently, the extraction decisions of their group members in subsequent rounds of play. In contrast, *myopic* (or short-sighted) users are only motivated to maximize their individual payoff in the current round of play.

Myopic users are assumed to adopt the common property strategy. The myopic user strategy, u_{mt} ,² is represented by:

$$u_{mt} = \begin{cases} \bar{u}_t & \text{when } x_t \leq \bar{X} - \frac{\gamma P_E \xi}{AS\delta} \\ 0 & \text{otherwise} \end{cases}, \quad (3)$$

where $\bar{u}_t$ is the maximum amount of water per period that the myopic user pumps as long as the condition $x_t \leq \bar{X} - \frac{\gamma P_E \xi}{AS\delta}$ is satisfied.

The decisions of the strategic user may be described by the dynamic optimization problem:

$$\begin{aligned} \max_{u_t} \quad & \sum_{t=1}^{\infty} \alpha^t J \left[\delta J u_t - u_t \left(\frac{\gamma P_E \xi}{(\bar{X} - x_t) AS} \right) \right] - C_0 \\ \text{s.t.} \quad & x_{t+1} = x_t + \frac{J u_t - R}{AS} \\ & x_t + \frac{J u_t}{AS} \leq \bar{X}, \end{aligned} \quad (4)$$

where J is the number of users extracting groundwater from the aquifer.³

We may then write the Bellman equation:

$$V(x_t) = \max_{u_t} \left[J \delta u_t - u_t \left(\frac{\gamma P_E \xi}{(\bar{X} - x_t) AS} \right) - C_0 \right] + \alpha V[x_{t+1}]. \quad (5)$$

The Bellman equation breaks down the infinite-horizon problem into a two-stage discounted function that we use to derive the optimal path of extraction.

From the Bellman equation we can derive the first-order conditions that yield the following Euler Equation:

$$J \delta - \frac{\gamma P_E \xi}{(\bar{X} - x_t) AS} = -\alpha \left[\frac{J u_{t+1}}{(\bar{X} - x_{t+1}) AS} - \frac{J \delta - \left(\frac{\gamma P_E \xi}{(\bar{X} - x_{t+1}) AS} \right)}{\frac{J}{AS}} \right] \frac{J}{AS}. \quad (6)$$

The Euler equation is used to derive the optimal path of extraction. In our equation, systematically increasing the value of gamma from 0 to 1 increases the cost in the present, $\frac{\gamma P_E \xi}{(\bar{X} - x_t) AS}$, but also increases the marginal (discounted) benefit in the future, $\frac{J \delta - \left(\frac{\gamma P_E \xi}{(\bar{X} - x_{t+1}) AS} \right)}{\frac{J}{AS}}$. Therefore, we may anticipate that changes in the subsidy will lead to a deviation in the optimal extraction path

Fig. 1. Optimal value function and optimal state path under status quo.

that, in turn, will further lead to a better steady level of the state variable.

We have tested the behavior of the model under status quo conditions ($\gamma = 0.2$, meaning a subsidy level of 80%), using parameter values from Salcedo et al. (2013) and the MATLAB package CompEcon by Miranda and Fackler (2002). The results are exhibited in the next set of graphs.

Fig. 1 shows on the vertical axis that the height of the water table increases and reaches a steady state around period 20, then continues zigzagging across the remaining periods. This zigzagging occurs because users switch on each period from the maximum extraction level to zero because the recharge rate makes it profitable to extract groundwater on every other period after the steady state is reached.

4. Policy interventions

This section moves beyond analyzing users' behavior when provided with an electricity subsidy for pumping groundwater to examine the effects of three different policy interventions: the elimination, reduction, and decoupling of the subsidy. To analyze the first two, we simulate the users' response by varying the value of γ from 0 to 1 in increments of 0.1. For this analysis, we use the parameters in the study by Salcedo et al. (2013) of users' behavior when pumping groundwater in the region of Aguascalientes, Mexico, which is one of the affected aquifers. We also use the CompEcon toolbox for MATLAB developed by Miranda and Fackler (2002). The model in our analysis was simulated for 100 periods, varying the parameter γ (the subsidy for electricity) from 0 to 1 in 0.1 increments.

Fig. 2 indicates that the steady state of the height of the water table (on the vertical axis) increases as the level of the subsidy (gamma) increases (on the horizontal axis) from 0 to 80 percent. This suggests that the subsidy to electricity influences the amount of water pumped from the aquifer and thereby results in deeper steady state of the water table levels for higher rates of subsidy.

Fig. 3 exhibits the level of the steady state for three different values of gamma. The highest levels of subsidy lead again to deeper levels of the water in the aquifer; furthermore, the time of convergence to the steady state is longer for higher levels of the subsidy.

One of the most relevant aspects to policy makers is finding out which policy achieves a shallower steady state in the shortest time possible. Fig. 4 demonstrates how many periods are required to achieve the steady state at each level of the subsidy e.g., 13 periods for gamma = 1). As might be expected, Fig. 4 resembles

² The subscript m represents the myopic user.

³ Given that we previously assumed that all farmers are homogenous, the subscript j is dropped.

Fig. 2. Height of the water table for different subsidy levels.

Fig. 4. Time of convergence to steady state.

Fig. 3. Optimal state path for different values of gamma.

Fig. 5. Optimal state path for different policy interventions.

Fig. 2 as the height of the water table is positively correlated with the number of periods by which a steady state is achieved.

The third policy instrument we evaluate is the decoupling of the subsidy from the electricity price. In this case, users receive a monetary transfer equivalent to their consumption during the last i periods.⁴ The optimization problem in this case is:

$$\max_{u_t} \sum_{t=1}^{\infty} \alpha^t J \left[\delta J u_t - u_t \left(\frac{\gamma P_E \xi}{(\bar{X} - x_t) AS} \right) \right] - C_0 + \frac{\sum_{k=t-i}^t \frac{u_k \gamma P_E \xi}{(\bar{X} - x_k) AS}}{i}. \quad (7)$$

The Bellman equation takes the form:

$$V(x_t) = \max_{u_t} \left[J \delta u_t - u_t \left(\frac{\gamma P_E \xi}{(\bar{X} - x_t) AS} \right) - C_0 \right] + \frac{\sum_{k=t-i}^t \frac{u_k \gamma P_E \xi}{(\bar{X} - x_k) AS}}{i} + \alpha V[x_{t+1}]. \quad (8)$$

This optimization problem is similar to the one presented in the last section, although here we include the decoupling of the

electricity subsidy $\frac{\sum_{k=t-i}^t \frac{u_k \gamma P_E \xi}{(\bar{X} - x_k) AS}}{i}$, which is calculated on the basis of the mean consumption of the last i periods ($i > 0$).

As in the first optimization model, the Bellman equation (Eq. (6)) is used to derive an Euler equation that sheds light on how the behavioral responses to changes in the subsidy affect the optimal path:

$$J \delta - \frac{\gamma P_E \xi}{(\bar{X} - x_t) AS} + \frac{\gamma P_E \xi x_t}{i} = -\alpha \left[\frac{J u_{t+1}}{(\bar{X} - x_{t+1}) AS} + \frac{\gamma P_E \xi u_{t+1}}{i} - \frac{J \delta - \left(\frac{\gamma P_E \xi}{(\bar{X} - x_{t+1}) AS} \right) + \frac{\gamma P_E \xi x_{t+1}}{i}}{\frac{1}{AS}} \right] \frac{J}{AS}. \quad (9)$$

This equation shows that the term $\frac{\gamma P_E \xi x_t}{i}$, which represents the marginal change in the decoupling transfer due to changes in the level of subsidy (γ), keeps the equation balanced, as it is added on both sides of the equation to the costs and benefits. Based on this observation, the behavior of the users under decoupling is expected to be either the same or close to the behavior under the subsidy elimination instrument.

The hypothesis to be tested experimentally is that changing the incentives by either eliminating or reducing the subsidy, or giving users a cash transfer decoupled from the electricity schedule results in a decrease in the amount of water pumped and in a higher steady state level of the water table.

⁴ The number of periods considered for calculating the mean consumption is i ; it ranges from 1 to $t-1$ for all $t > 2$.

Fig. 6. Extraction path comparison: Status quo vs. decoupling.

The results portrayed in Fig. 5 represent a comparison between the status quo, subsidy reduction from 80% to 50% rate, and 15 periods for calculating the mean decoupling factor. Decoupling accomplishes a steady state of the height to water table that is lower than reducing the subsidy to 50%. These results suggest that of the three policy interventions proposed in our study the decoupling is the most viable policy.

The optimal strategy for myopic users is to extract the maximum amount of water possible (we set a limit of 10 units in our experiment) until it is no longer profitable. Fig. 6 exhibits the extraction path for the cases of decoupling and status quo (elimination and reduction follow the same path as decoupling because myopic users care only about maximizing the current period profit). The behavior exhibited in Fig. 6 demonstrates why the steady state of the height of the water table fluctuates over periods. After a specific height is reached, extracting water is no longer profitable; however, the recharge rate renders extraction profitable in the next period.

5. Laboratory experiments

We tested the descriptive power of the analytical results in the laboratory. To ensure robustness and statistical power of the experiments, we recruited for each of the four conditions five groups of six members each for a total of 120 subjects. All the participants in each of the three policy interventions first played the status quo game (Condition 1), and then proceeded to play one of the policy interventions (reduction, elimination, or decoupling). The control groups played the status quo in both parts of the experiment. The subjects were randomly assigned to groups. No communication among the subjects was allowed during the experiment.

The participants were mostly undergraduate students who volunteered to take part in a decision making experiment with payoff contingent on their performance. Many of them resided in Southern California, and therefore were frequently exposed to media information about recurrent droughts, shortage of water for irrigation, and the dire consequences of overexploitation of groundwater.

The experiment was conducted in a large laboratory. The participants were seated in individual cubicles that prohibited communication. They were recruited through an automated online system from a pool of all undergraduate students at the University of California Riverside (UCR); none of the students had participated previously in similar experiments.⁵ Sessions lasted no longer than two hours, including check-in and payment time. The mean payoff across all five conditions was \$29. The procedures for the five conditions are summarized below. The instructions to the participants, as well as the parameters of the simplified model used for the calculation of water depth, payments, and profits are provided in an auxiliary appendix that is available on the journal website.

5.1. Condition 1: status quo (No changes to the subsidy)

Subjects in Condition 1 were instructed to request an amount of water to be pumped from the aquifer. The water table level at the beginning of each period was commonly known by the group members. The subjects were provided with a schedule that listed the profits for each combination of the height of the water table and the set of possible requests. Once the group members submitted their requests, they proceeded to the next period where they were informed of the new height of the water table. The extraction game had an infinite horizon; each round was terminated randomly, with probability p set at $p = 0.15$,⁶ or continued for at least one more period, with the complementary probability of 0.85. At the end of the session, the subjects were paid contingent on their performance (profits were stated in tokens).

5.2. Condition 2: reduction of subsidy

Subjects in this condition were instructed to request an amount of water to be pumped from the aquifer. They faced a reduction in the amount of subsidy (from 80% to 50% of the electricity price

⁵ In order to infer the lab results we have replicated our experiment with a field study with farmers in Mexico (Tellez-Foster et al. 2016c).

⁶ This is following the experimental procedure for infinite horizon used by Suter et al. (2012).

subsidized). As in Condition 1, they were informed of the height of the water table and the profit conditional on the aggregate group request.

5.3. Condition 3: elimination of subsidy

Subjects in Condition 3 implemented the same task as in Conditions 1 and 2, with the same per period termination probability of 0.15. For this condition, the subsidy was removed completely.

5.4. Condition 4: elimination of subsidy and transfer of payment (Decoupling)

In Condition 4, the subjects performed the same task as in Conditions 1 and 2. However, after 15⁷ consecutive periods, they were told that the subsidy would be removed (setting $\gamma = 1$), that their individual mean subsidy would be calculated, and that they would be granted a token transfer equivalent to the subsidy they received during the first 15 periods of the first part (Condition 1).

5.5. Condition 5: control

In Condition 5, the subjects performed the same task as in Condition 1. After the random termination of Part 1, they proceeded to play the same game as under Condition 1 with the same subsidy level ($\gamma_t = 0.2$) until it was terminated randomly. This condition was conducted to gather data on subject behavior under no treatment in order to establish a baseline for comparing and calculating the treatment effects of the previous three treatments.

6. Results

We compare below only the results of Condition 1 with the policy treatment conducted in each of the other conditions; we do not compare the status quo results across conditions due to the different characteristics of each group being exposed to the status quo and the treatment conditions. Determining the difference in the subsidy structure entails comparing groups both pretreatment and post treatment, but does not require a cross-comparison between pretreated and post-treated groups.

6.1. Elimination

For the elimination condition, we recruited 30 undergraduate students to form five groups of six members each. Subjects read the instructions at their own pace. This was followed by a brief oral summary and a short question-and-answer period. This same procedure was implemented for all the other conditions.

In this subsection, we compare group results for the status quo and elimination conditions. Fig. 7 exhibits the mean total requests of the groups who played these two conditions. It demonstrates that as subjects adapt to the policy change in periods 1–3, they play the strategy that they used consistently in Part 1 of the experiment (status quo condition). As they realize that pumping becomes more expensive, they lower their requests consistently.

Fig. 8 displays the mean height of the water table across groups. The mean height of the water table in the status quo condition is consistently but slightly lower up to the 7th period. In the last two periods this trend is reversed, and the height of water table for the elimination condition stabilizes, whereas the one for the status quo condition accelerates monotonically across the ten periods.

Fig. 7. Mean total request by group. Elimination condition.

Fig. 8. Mean Height of the water table. Elimination condition.

6.2. Reduction

The subjects in the reduction condition performed the same task that they completed in Condition 1, except that in this case they faced a reduction in the subsidy from 80% to 50% (changing $\gamma = 0.2$ to $\gamma = 0.5$).

Fig. 9 illustrates the mean request for the status quo and reduction conditions. With the exception of round 9, mean requests across groups for the status quo condition were relatively stable across periods, ranging from 44 to 50. In contrast, subjects in the reduction condition increased their requests steadily across the 13 periods from 36 to 55.

The effect of the change in policy is displayed in Fig. 10. The mean height of the water table across groups is consistently lower in the reduction condition compared with the status quo condition, although the difference between these two conditions never exceeds 11 m.

6.3. Decoupling

The procedure in the decoupling condition was similar to the procedure in the previous two conditions. The major exception was that the requests were recorded, and at the end of period 15 (Part 1 of the experiment) the mean cost was computed and each subject was informed that the subsidy had been removed and re-

⁷ We used 15 periods to reduce bias for periods of high requests or low requests, as explained in Tellez Foster et al. (2016b).

Fig. 9. Mean total requests per group. Reduction condition.

Fig. 11. Mean total requests per group. Decoupling condition.

Fig. 10. Mean height of the water table. Reduction condition.

Fig. 12. Mean height of the water table. Decoupling condition.

placed by a token transfer (lump-sum subsidy). The token amount was equivalent to the mean individual request in Part 1 of the experiment; it was granted at the end of each subsequent period in Part 2, regardless of the requests in Part 2 of the experiment.

The effect of decoupling the subsidy is the strongest among all the treatment conditions. Fig. 11 shows that the mean request per group is significantly lower once the subsidy is decoupled. This is reaffirmed when we observe the height of the water table in Fig. 12, where it is evident that once the subsidy is decoupled the pace at which the aquifer becomes deeper decreases creating a gap between the height of the water table under the status quo and decoupling treatments.

6.4. Control

For comparative purposes, we also conducted a control experiment in which the subjects played the status quo condition in both parts using the same procedure as in the previous conditions. The results (Figs. 13 and 14) suggest that subjects tended to play more aggressively in the second part of the experiment, when they acquired better understanding of how to play. The results reported above allow us to capture any unobservable variable that may affect the requests so that we can calculate the treatment effect more accurately.

7. Effectiveness of the policy interventions: an econometric analysis

In this section, we analyze the treatment effect of each condition, provide a quantitative analysis of the behavior of the participants under the different conditions, and use the results as a basis for drawing policy implications. For the purpose of this experiment, we will use the difference in differences method since it allows us to compare the difference in extractions between the different conditions.

The difference in differences estimation method is a common technique in the literature. It determines the effect of the treatment across individuals with similar characteristics, uses counterfactual scenarios to observe the behavior of individuals who have not received the same treatment, and compares it to that of the individuals who did. This technique has widely been used in the economic literature. In a milestone study, Card and Krueger's (1994) estimated the effect of employment after the increase in minimum wage in New Jersey.

We chose the difference in differences method to compare the effectiveness of the policy interventions. We estimated a series of econometric models in an attempt to capture the quantitative effect of the change in subsidy level on the requests for water. To ensure sound and robust estimations, we repeated this process 1000 times by bootstrapping from a uniform distribution with

Fig. 13. Average total requests per group.

Fig. 14. Average height of the water table.

random drawings. We then estimated the effects of the treatment using the following model:

$$\Delta w = \beta_1 \text{ Pretreatment} + \beta_2 \text{ Posttreatment} + \beta_3 \text{ Interaction term (pre} \times \text{post)},$$

where Δw is the change in the request for water after the treatment is applied, β_1 is the estimator for the status quo (Pretreatment) condition, β_2 is the treatment estimator, and β_3 is our relevant estimator where we obtain the final effect of the treatment.

Next we present the estimations for the three treatments in three separate tables. Table 1 shows that the sign of the treatment effect is negative. It is statistically significant as expected, revealing that on average eliminating the subsidy reduces the requests by 0.789 units of water per individual for each period. Even though the effect may seem small, it is the cumulative effect of each diminished request that yields a better outcome as compared with the status quo condition.

In the reduction treatment, Table 2 indicates a stronger effect when compared to the control group. In this case, we observe that the subjects reduced their request on average by 1.534 units per period (compared to -0.789 for the elimination condition). This result does not coincide with our initial prediction, where the reduction condition treatment effect seemed smaller as compared to the other two conditions; however, the sign is negative as expected and statistically significant.

Table 1

Treatment effect estimation. Elimination condition.

Number of observations in the Diff-in-Diff: 1032				
	Baseline	Follow-up		
Control:	246	318	564	
Treated	234	234	468	
	480	552		
	Request	S. Err.	t	P> t
Baseline				
Control (C)	7.264			
Treatment (T)	7.333			
Diff (T-C)	0.069	0.249	0.28	0.781
Follow-up				
Control (C)	8.041			
Treatment (T)	7.321			
Diff (T-C)	-0.720	0.235	-3.07	0.002***
Treatment effect	-0.789	0.342	-2.31	0.021**

Inference: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Table 2

Treatment effect estimation. Reduction condition.

Number of observations in the Diff-in-Diff: 1086				
	Baseline	Follow-up		
Control:	246	318	564	
Treated	258	264	522	
	504	582		
	Request	S. Err.	t	P> t
Baseline				
Control (C)	7.264			
Treatment (T)	7.810			
Diff (T-C)	0.546	0.226	2.41	0.016**
Follow-up				
Control (C)	8.041			
Treatment (T)	7.053			
Diff (T-C)	-0.988	0.211	-4.68	0.000***
Treatment effect	-1.534	0.309	-4.96	0.000***

Inference: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

Table 3

Treatment effect estimation. Decoupling condition.

Number of observations in the Diff-in-Diff: 1224				
	Baseline	Follow-up		
Control:	246	318	564	
Treated	336	324	660	
	582	642		
	Request	S. Err.	t	P> t
Baseline				
Control (C)	7.264			
Treatment (T)	8.979			
Diff (T-C)	1.715	0.195	8.79	0.000***
Follow-up				
Control (C)	8.041			
Treatment (T)	7.741			
Diff (T-C)	-0.300	0.183	-1.64	0.10*
Treatment effect	-2.015	0.268	-7.53	0.000***

Inference: *** $p < 0.01$; ** $p < 0.05$; * $p < 0.1$

The decoupling treatment (Table 3) yielded the strongest effect among all conditions, with a reduction in the average request per subject of 2.015 units. This result indicates that the subjects responded more forcibly in response to decoupling the subsidy than to its reduction or elimination. This result may be explained by a behavioral change to a more conservative strategy after receiving the transfer lump-sum every period.

8. Conclusions and policy implications

This paper analyzes the effects of subsidy structures and policy modifications on the sustainability of groundwater, given the per-

verse incentives of electricity subsidies for groundwater pumping in the farming sector. By embedding the subsidy into the cost function, we have measured the effect of different policy interventions. Our analysis gives rise to several conclusions that are reported below with respect to various institutional arrangements and policy decisions.

8.1. Comparing the predictions with the experimental results

By comparing the observed behavior of the subjects to the predicted behavior, we find that all three policies have a positive effect on the water requests; decoupling the subsidy produces the strongest effect among the three in support of our hypothesis that this intervention method yields the most desirable results.

Despite the theoretical predictions indicating that elimination and decoupling would produce similar effects, we find that the elimination condition sustains the least effect among the three conditions. This result may be attributed to the more conservative strategy that the subjects adopted during the first part of the experiment, which captured a smaller effect when compared to the reduction in or decoupling of the subsidy.

In the reduction condition, the subjects chose a more aggressive strategy in the first part of the experiment, and when they faced a reduction in the subsidy they adopted a more conservative approach. The group's behavior across treatments was different when playing Condition 1: some groups acted more conservatively in the first part of the experiment, as demonstrated in the elimination condition, whereas other groups acted in a more aggressive manner, as in the reduction and decoupling conditions. This result is attributed to the change in the subject's expectations rather than in the experimental design.

8.2. Policy implications

The joint results of the simulations and the experiment suggest that farmers may reduce water pumping when the subsidy for electricity is modified by reduction, elimination, or decoupling. The importance of this finding is that, given the political power that farmer organizations bear and the strong lobby that they mobilize, it is politically infeasible to eliminate the electricity subsidy. We propose a different policy alternative to address this problem with lower social/political cost. Our results support the conclusion that decoupling is a feasible policy modification for achieving the stabilization of over-drafted aquifers. In addition, decoupling would have similar effects as drastically reducing or completely eliminating the subsidy with a considerably weaker political burden instigated by the latter policies.

Auxiliary Appendix

This Auxiliary Appendix refers to the Decoupling Condition and is introduced as an example of the procedures we used in the various conditions in this experiment. Readers interested in the instructions for the Elimination and for the Reduction Conditions may receive them upon request from the corresponding author.

Instructions for experiment on common pool resource dilemmas

Welcome to an experiment on common pool resource dilemmas. During the present experimental session you will be asked to make a large number of decisions and so will the other members of your group. Your decisions, and the decisions of the other participants, will jointly determine your monetary payoff (paid at the end of the session) according to a procedure that will be explained below. In the present experiment, you will be earning tokens that will be converted into dollars at the end of the session.

Please read the instructions *carefully*. If at any time during the session you have questions, please raise your hand and the experimenter will come to assist you. Please keep the instructions on your desk as you may wish to refer to them during the session.

Please note that from now on all communication between the participants is prohibited. If the participants communicate with one another in any shape or form, the session will be terminated. Please note, too, that the experiment is self-paced. Once all the participants submit their decisions, the experiment will move to the next stage. Therefore, you may anticipate short delays while other participants in your group determine and then submit their decisions. The experiment is divided into two parts. Instructions for Part I are provided below, whereas the instructions for Part II will be provided to you once all the groups complete the assignment in Part I. You will be paid for your participation in both parts of the experiment; therefore, we ask you to read the instructions of both parts.

PART I – Status Quo

Statement of the task: Consider the case of a farmer who has to pump water regularly (say, once a week) from an aquifer. Other farmers also pump water regularly from the same aquifer. As is the case in many countries, the government subsidizes the farmers by charging them a cheaper price for electricity used to operate the pumps. In this case, your subsidy is 80% of the electricity cost, meaning that you are only charged 20% of the actual pumping costs. The profit of each farmer depends on the amount of water he/she pumps, the amount paid for the electricity he/she used, the amount of water pumped by all the farmers from the same aquifer, and the consequent depth of the water level in the aquifer, which is measured in meters from land surface (it costs more to pump water from a deeper level). As explained below, you' ll be asked to participate in several **rounds** of this decision task, each round including multiple **periods**. In each period, you' ll be asked to submit in writing the number of water units you intend to pump. This is the only decision that you' ll be asked to make.

Description of the task: At the beginning of the session, you will be assigned at random to a group of six participants. The composition of the group will remain fixed for the entire session. Communication with other members of the group is strictly forbidden.

In each period, you will be asked to determine the number of units of water that you intend to pump. In the same way, the other members in your group will be asked to determine their requests for water. Note that the more units you pump, the higher is your revenue but the deeper is the water level in the next period, and, consequently, the higher is the cost of pumping. This is the dilemma faced by each farmer. The same holds for any other member in your group. Clearly, in any round of play the depth of the water level in the next period depends on the extraction decisions made by **all** the members of your group in the present period. That is, the requests made by the group this period will affect the level of water next period. At the end of the period you will be informed of the new depth of the water table in the aquifer. The maximum number of units of water that you may request at any given period is **10**.

When you are asked to submit your request, you will be presented with a table that lists the payoffs associated with different requests that you may make. As is typically the case, your payoff for the period is equal to the **revenue** you earn minus the **cost** of extracting the water. To know your profits associated with any possible request (minimum **0** and maximum **10** units of water), you will observe the current depth of the water table and then determine the amount of water you wish to pump (See Chart below).

Revenue. Denote the number of water units that you intend to pump in a given period by X . If you choose to request X units of water, then your *revenue* will be proportional to this amount.

Range of depths 51-100

Units of Water extracted	0	1	2	3	4	5	6	7	8	9	10
Depth of the water	51	52	53	54	55	56	57	58	59	60	61
Amount requested	0.0	8.1	16.2	24.2	32.3	40.4	48.5	56.6	64.6	72.7	80.8
Profit	0.0	8.1	16.1	24.2	32.3	40.3	48.4	56.5	64.6	72.6	80.7

Range of depths 1-50

Units of Water extracted	0	1	2	3	4	5	6	7	8	9	10
Depth of the water	24	30	36	42	48	54	60	66	72	78	84
Amount requested	0.0	8.3	16.5	24.8	33.1	41.3	49.6	57.8	66.1	74.4	82.6
Profit	0.0	8.3	16.5	24.8	33.1	41.3	49.6	57.8	66.1	74.3	82.5

Range of depths 1-50

Units of Water extracted	0	1	2	3	4	5	6	7	8	9	10
Depth of the water	24	30	36	42	48	54	60	66	72	78	84
Amount requested	0.0	8.3	16.5	24.8	33.1	41.3	49.6	57.8	66.1	74.4	82.6
Profit	0.0	8.3	16.5	24.8	33.1	41.3	49.6	57.8	66.1	74.3	82.5

Table A.1

Profits associated with different aquifer depths (30 m, 50 m, 100 m and 200 m).

Units of Water extracted	Depth			
	30	50	100	200
0	0.0	0.0	0.0	0.0
1	9.7	9.6	9.5	8.5
2	19.3	19.2	19.0	16.9
3	29.0	28.9	28.5	25.4
4	38.6	38.5	38.0	33.9
5	48.3	48.1	47.5	42.4
6	57.9	57.7	56.9	50.8
7	67.6	67.3	66.4	59.3
8	77.2	76.9	75.9	67.8
9	86.9	86.6	85.4	76.2
10	96.5	96.2	94.9	84.7

Water table level in the next period: The water table level in the next period, which we denote by $Y(\text{next})$, depends on (1) the total extraction of water by all the 6 members of your group, and (2) a recharge rate (e.g., precipitation) that is set at 30 per period. Thus, the water table levels in the present period (denoted by $Y(\text{present})$) and in the next period ($Y(\text{next})$) are related by

$$Y(\text{next}) = Y(\text{present}) + 0.32 \times (\Sigma X_t - 30).$$

In other words, the water level in the next period, $Y(\text{next})$, depends on the water level in the present period $Y(\text{present})$ plus the (difference between the total requests in the present period minus 30), which is multiplied by a constant 0.32, which is the effective amount of the recharge that remains in the aquifer.

Example 3. Assume that the request for water by each member of the group in the present period is 10 units (for a total of $10 \times 6 = 60$ units for the group). Assume, also, that the present water level is 100 m deep. Then, the water level in the next period is $Y(\text{next}) = 100 + 0.32 \times (60 - 30) = 109.6$ (depth will be rounded up to the next integer)

In this case, the depth of the water table increases from 100 to 109.6, and since we round to the next integer we say it increases to 110.

Example 4. For yet another example, assume the same recharge rate as in Example 3 and the same initial depth of the water table level. However, rather than requesting 10 units as before, assume that the group members jointly request 18 units. Then, the water table level is calculated as

$$Y(\text{next}) = 100 + 0.32 \times (18 - 30) = 96.16 \text{ (we round up to the closest integer).}$$

Due to the lower requests the depth of the water table in this example decreases.

Procedure: At the beginning of each round of play you will be informed of the period number, the recharge value (30), the depth of the water table in the aquifer, and your current earnings. The periodical recharge value will stay the same for all periods, whereas the depth of the aquifer may change from period to period (as illustrated in Examples 3 and 4), depending on the amount of water extracted by the group. It may not go below 0 (which is the case when the aquifer is full) and it may not exceed 250 m, which is the maximum depth of the aquifer. In each period, you may request any amount up to 10 units of water.

You will be given a form and asked to submit your request for the period in writing without disclosing it to anyone else. Once all the 6 members of your group have submitted their written requests, the experimenter will calculate and then inform the group of the new depth, and privately inform each individual of his/her earnings (they will be written on the sheet that you use to submit your requests).

Cost. The cost that you incur is calculated by a formula that is not presented here. However, it is illustrated below in a table. The production cost includes a fixed cost for pumping water that is not related to the number of water units you extract and a variable cost that depends on the price of electricity per unit water pumped and the depth of the aquifer.

Profit. Your profit is computed using the formula below:

$$\text{Profit} = \text{Revenue} - \text{Cost}$$

Please consider the following examples.

Example 1. Let the depth of the aquifer be 30 m and assume that you extract 10 units of water. Then, your revenue for the period is given by 100. Your cost for this period is calculated to be 17.4. Therefore, your profit is $100 - 17.4 = 82.6$ (See table for Example 1, below).

Example 2. For a second example, assume as before that the depth of the aquifer is 30 m and that you extract 6 units of water. Then, your revenue for the period is 60. Your cost for this period is calculated to be 10.4. And your profit is $60 - 10.4 = 49.6$ (See table for Example 2, below).

Table A.1, which is displayed below, is critical for determining your decision. The left column of Table A.1 presents profits associated with alternative requests for different number of units, assuming that the water table level in the present period is 30 m deep. Several additional depths (50, 100, 200) are also presented in the table.

"Reforming the Electricity Subsidy for Groundwater Extraction: A joint Laboratory Experiment and Field Study"

Condition: Round:

Group:

Subject:

	Depth	Request	Profit
t1	30		
t2			
t3			
t4			
t5			

Fig. A1.

Fig. A1 above shows the requests sheet. In each period, please write down your request in the designated box and turn it in to the staff conducting the experiment. After computing your profits your sheet will be returned to you with your profit for that period and the water table for the next one. This procedure will be repeated until further instructions are given.

In the present experiment, the number of periods is not fixed in advance. Rather, the number of periods in each round that you'll actually play will be determined by the computer as follows. At the end of each period, the computer will use a random device (a table of random numbers) and terminate the round with probability of 15 percent. Clearly, with the remaining probability of 85 percent, the group will proceed to the next period.

At the end of the session, your profits across all the rounds will be summed up by the computer. Then, the sum will be converted to dollars at the rate 500 tokens=\$ 1.00. Your payoff for the experiment will be awarded to you privately. After completing the two parts of the experiment, you will be asked to sign a receipt, and then you'll be paid off for your participation.

PART 2 – Decoupling

Welcome to Part 2 of the experiment. Please read this new set of instructions carefully as the new task that you are required to perform might have changed.

Your decisions, and the decisions of the other participants, will jointly determine your monetary payoff (paid at the end of the session) according to the same procedure as in Part 1.

If at any time during Part 2 you have questions, please raise your hand and the experimenter will assist you. Keep the instructions on your desk as you may wish to refer to them later during the session.

As in Part 1, all communications between the participants is prohibited. Once all the participants submit their decisions, the experiment will proceed to the next stage. Therefore, you may anticipate short delays while other participants determine and then type in their decisions.

Statement of the task: Part 2 of this experiment is the same as Part 1, except of the nature of the subsidy. In Part II, you will be assigned a different type of subsidy. Specifically, you will now receive a *fixed amount* of tokens for each period that will be calculated on the basis of your average requests in Part 1; in other words, in Part 2 you will pay the full pumping costs but you will receive a *fixed* number of tokens per period regardless of your pumping decisions. This fixed number of tokens is called "*decoupling transfer*". You will be informed of the amount of decoupling transfer that you are entitled to at the beginning of the round, and this amount will remain fixed for the duration of the session. Because your profits may be affected by this new payment arrangement, you will receive a new table of profits. Similarly to the one in Part 1, the profit of each participant in the experiment depends on the amount of water he/she pumps, the amount paid for the electricity he/she used, the decoupling transfer, the amount of water pumped by all the farmers from the same aquifer, and the consequent depth of the water level. As explained below, you'll be asked to partici-

Depth of the water

Range of depths	Units of Water extracted	Amount requested	Profit
51-100	0	51	0.0
	1	8.1	8.1
	2	16.2	16.2
	3	24.2	24.2
	4	32.3	32.3
	5	40.4	40.3
	6	48.5	48.4
	7	56.6	56.5
	8	64.6	64.6
	9	72.7	72.6
	10	80.8	80.7

pate in several **rounds** of this decision task, each including multiple **periods**. In each period, you'll be asked to submit in writing the number of water units you intend to pump. This is the only decision that you'll be asked to make in each period.

Description of the task: At the beginning of Part 1, you were assigned at random to a group of six participants (farmers), this group will remain unchanged in Part 2. Communication with other members of the group is strictly forbidden.

At the beginning of Part 2, you will be informed of your decoupling transfer. This transfer has been calculated based on the average units of water you requested in Part I of the experiment and the associated costs of pumping that amount of water.

Similarly to Part 1, you will be asked to determine the number of units of water that you intend to pump in each period. The other members of your group will be asked to do the same. Note that the more units you pump, the higher is your revenue but the deeper is the water level in the next period and, consequently, the higher is the cost of pumping. The same holds for any other member of your group. Clearly, in any round of play the depth of the water table in the next period depends on the extraction decisions made by all the members of your group in the present period. That is, requests made this period by the group will affect the level of water next period. At the end of the period, you will be informed of the new depth of the water table in the aquifer.

When you are asked to submit your request, you will be presented with a table that lists the payoffs associated with the different requests that you may submit. As before, your payoff for the period is equal to the **revenue** you earn minus the **cost** of extracting the water plus the decoupling transfer. To know your profits associated with any request that you may submit (minimum 0 and maximum 10 units of water), you will check the current depth to the water table and then determine the amount of water you wish to pump.

Please study the examples below.

Example 1. Assume that in Part 1 your average request for units of water was 7 and the associated pumping costs to that request were 12; therefore, your decoupling transfer will be 12 tokens.

Assume that the depth of the aquifer is 30 m and that you extract 10 units of water. Then, your revenue for the period is given by 100. Your cost for this period is calculated to be 17.4. And your profit is $100 - 17.4 = 82.6$. Then you will add the decoupling transfer (12 tokens) and your final profit for the round will be: $82.6 + 12 = 94.6$.

Please note that the parts in red and orange are shown only for illustration purposes. The table you will receive will only reflect the parts in blue; however you will be informed of your final profit in each period

Example 2. As in Example 1, your decoupling transfer is 12. You are informed that the new level of water in the aquifer is 226. At this level you decide to pump zero units of water, meaning that

Depth of the water

Range of depths 1-50	Units of Water extracted	Depth of the water			Transfer	Final profit
		0	30	100		
		0.0	0.0	0.0	+12	12.0
		8.3	8.3	8.3	+12	20.3
		16.5	16.5	16.5	+12	28.5
		24.8	24.8	24.8	+12	36.8
		33.1	33.1	33.1	+12	45.1
		41.4	41.3	41.3	+12	53.3
		49.6	49.6	49.6	+12	61.6
		57.9	57.8	57.8	+12	69.8
		66.2	66.1	66.0	+12	78.1
		74.4	74.4	74.3	+12	86.4
		82.7	82.6	82.5	+12	94.6

Amount
requested

Profit
With no transfer

Final Profit

your profit associated with water use is zero. However, you still receive the decoupling transfer so that your final profit for the period will be: $0 + 12 = 12$.

Water level in the next period: The water level in the next period, which, we denote by $Y(\text{next})$, depends on (1) the total request of water across all 6 members of the group, and (2) a recharge rate (such as precipitation) that is set at 30. It is computed exactly as in Part 1. To remind you, the water level on the present (denoted by $Y(\text{present})$) and next period are related by

$$Y(\text{next}) = Y(\text{present}) + 0.32 \times (\sum X_t - 30).$$

In other words, the water level in the next period, $Y(\text{next})$, depends on the water level in the present period $Y(\text{present})$ plus the (difference between the total requests in the present period minus 30), which is multiplied by the constant 0.32, which was explained earlier.

Example 3. Assume that the request of each member of the group in the present period is 10 units (for a total of $10 \times 6 = 60$ units for the entire group). Assume also that the present water table level is 100 m deep. Then, the water table level in the next period is

$$Y(\text{next}) = 100 + 0.32 \times (60 - 30) = 109.6 \text{ (depth will be rounded to the next integer)}$$

In this case, the depth has increased from 100 to 109.6.

Procedure: The procedure for Part 2 is exactly as the one for Part 1 (Page 6).

Payment: At the end of the session, your profits across all the rounds will be summed up by the computer. They will be converted at the rate 500 tokens = \$1.00. At the end of this second part you will be informed privately of your total earnings of both parts of the experiment. You will be asked to complete and sign a receipt and then you will be paid for your participation.

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