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

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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.

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 subsiding 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

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

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.