OPTIMAL TAXES IN EXTRACTION FROM A SPATIALLY EXPLICIT AQUIFER: EXPERIMENTAL EVIDENCE

by

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ABSTRACT

Groundwater resources for drinking water and irrigation are increasingly stressed. They are also common pool resources (CPRs) with incentives leading to potential overuse. Many papers have replicated myopic extraction—in effect, a congestion externality—and the resulting social suboptimality that occurs in intertermporal games. Only a few, however, have produced this in a spatially explicit setting that can be tested in the lab. This paper uses experimental economics techniques and extends this literature with a set of price-based incentive policies. Further, this research considers modified tax policies, which lessen the distributional burdens on users, and also ask research participants their opinions of the different policy instruments at the conclusion of the session.

This set of experiments builds on the spatially explicit aquifer first reported in Li et al. (2014). The first task was to derive an optimal intertemporal tax. Numeric optimization was carried out by linking software of Modflow and MATLAB, to derive a single intertemporal tax that incentivizes users to undertake extraction decisions that maximize the value of the aquifer. The experiments were carried out using the optimal marginal tax rate under various distributive configurations. Specifically, the treatments used instruments of thresholds or side payments to generate different distributive outcomes, which theoretically should not have influenced behavior. In addition, a baseline treatment was conducted that did not involve a tax.

Participants were recruited to participate in the experiment as groundwater users in May 2014 at the University of Delaware. Seventy-two undergraduate students

from economic majors were recruited and 72 × 71 individual choice combinations were collected in the experiment. Each experiment session lasted approximately two hours and participants earned approximately $30 based on their decisions and on the decisions of others sharing a common aquifer.

The results show that, compared with baselines, the pumping rates in each round of the tax treatments decrease significantly. This indicates that tax instruments have the potential to reduce groundwater use. However, all of the pumping rates in the tax treatments fall below the optimal pumping path in most rounds. The systematic deviation from the optimal path indicates that the effect of tax policies tends to be slightly excessive. In addition, all of the pumping decisions in each round of tax policies are clustered, supporting the theoretical design that all tax treatments provided the same marginal incentive and participants recognized these incentives. However, the threshold and side-payment treatments produced very different welfare impacts for the respondents. The most important finding was that one side-payment treatment was able to generate the same similar welfare impacts on the users as the baseline, but was also able to drive the respondents closer to the intertemporally socially optimal usage rates.

Surprisingly, participants' opinions on the different tax policies did not always match their received welfare. Participants tended to rate the tax treatments without redistribution of tax revenue very low. This can be explained because they gained less profit than the unregulated scenario. Surprisingly, participants also rated the tax treatment with side payments lower than the unregulated scenario in all of the rating aspects although they earned higher profits during these treatments. A potential explanation is that groundwater users simply reject policy interventions such as tax policies. The fixed-effect model addressed the positive impact of profits on participants' rating of a policy as beneficial to individual and group, while the tax policy has a negative effect on rating as in opinions. The final effect is that the positive effect is counterbalanced by a negative effect probably due to the rejection of tax policy. The results also indicate that the negative impact of tax policy on user rating tends to be smaller with higher levels of the tax threshold. The tax treatments with redistribution of tax revenue also decrease the negative impact on rating.

Chapter 1

INTRODUCTION

Groundwater is one of the most important natural resources for agricultural, industrial and residential use in United States. According to a recent U.S. Geological Survey in 2005, fresh groundwater withdrawals in United States were 79.6 bgal/d (billion gallons per day), accounted for 19.4% of total national water withdrawals and about 67% of the irrigation and 18% of the public supply in the United States (Kenny et al., 2009). As groundwater resources for drinking water and irrigation are increasingly stressed, the extraction of groundwater as well as the aquifer depletion increases rapidly. The daily groundwater withdrawal and consumption doubled in the past 50 years, ranging from 34 bgal/d in 1950 to 82.6 bgal/d in 2005 (USGS, 2005).

Groundwater is a typical example of common property resources (CPRs) with incentives leading to potential overuse. Aquifer users act myopically and extract water quantity to maximize their individual profits. This quantity of extracted water, which is larger than the socially sustainable utilization, leads to the significant groundwater depletion. Economically, groundwater overuse is usually treated as a representative example of tragedy of the commons (Mulligan et al., 2014). To maintain groundwater sustainable usage and correct the negative externalities from market failure, various policy interventions have been discussed. Koundouri (2004) summarized these popular policy instruments related to groundwater depletion: “government-push” approaches (eg. extraction tax, water use quota and subsidy), “business-led” initiatives (eg. water market institutions), and “self-regulation programs” (eg. voluntary agreement). Among all the policies instruments, a tax policy provides an effective price signal or incentive to conserve groundwater.

A tax policy forces groundwater users to consider their future and neighboring users' economic values, which are ignored in an unregulated market (Bredehoeft and Young, 1970). Madani and Dinar (2013) summarized the three main methods to impose taxes on groundwater users: pumping cost form, utility form, and pumping rate form. We adopt the most direct method which imposes tax on groundwater users' extraction. The efficiency of a tax policy greatly depends on the design of the tax rates. Ditwiler (1968) indicated that a low level tax rate would lack the incentive to reduce the misallocation of groundwater CPRs. Bredehoeft and Young (1970) varied the tax from zero to $25 per acre-foot to identify the best tax rate, which maximize the net economic yield. However, the simulation model of a single-cell aquifer greatly affects the reliability of results. Mulligan et al. (2014) varied tax rates from $2 to $18 per 1000 ft^3 and indicated that $4 per 1000 cubic feet or less is the optimal level for groundwater user and the streamflow violation. In spite of the simulation and groundwater model they use, the aquifer characteristics and groundwater mobility are so complicated to simulate that the potential implication of optimal level of tax rate is very limited. Instead of seeking the optimal level of tax rate as the object of research, this study derived an optimal intertemporal tax as the "upper-bound" of groundwater management to assess the efficiency of various price-based incentive policies.

The implementation of tax policy instruments will significantly reduce groundwater exploitation (Feinerman and Knapp, 1983; Mafani and Dinar 2013; Mulligan et al., 2014). However, the tax policy also transfers some benefits from groundwater users to nonusers (Feinerman and Knapp, 1983) and many users would potentially be forced out of business in the long run (Maddock et al., 1975). In other words, the tax policy might be undesirable because of the problems involved in the redistribution of tax revenue—tax revenue that must be generated to get incentives "right". To avoid users' enormous welfare loss in a tax policy situation, some kinds of redistribution of tax revenues should be implemented (Bredehoeft and Young, 1970; Mafani and Dinar 2013; Mulligan et al., 2014). The most direct way to redistribute tax revenues is to set the tax revenue equal to the welfare loss imposed by the tax (Mulligan et al., 2014). The maximum tax revenue will ensure that users' total profit equals the zero-tax case (Madani and Dinar, 2013). However, if users are to perceive gains from management which are approximately equal to what they paid out, the incentive effect of the tax will be lost and groundwater users would not systematically change their extraction behavior in CPR. Therefore, it is challenging to construct a tax revenue redistribution system that not only minimizes users' welfare loss because of the implementation of the tax policy, but also ensures the effectiveness of the tax policy on groundwater withdrawal. This paper considers several modified tax policies, which lessen the distributional burdens to groundwater users.

Assessing the efficiency of groundwater management policy relies on the construction of optimal and myopic extraction strategies. However, observing physical aquifers in the real world is challenging since the aquifer motion varies over both time and space. The aquifer simulation started from the single-cell aquifer or "bathtub" model (Gisser and Sanchez, 1980; Feinerman and Knapp, 1983; Burness and Brill, 2001). In the bathtub model, the features of the groundwater resource are usually expressed by a single parameter: the aquifer volume or the pumping lift (Brozović et al., 2010). With the bathtub model, Gisser and Sanchez (1980) conclude that there is no significant different between myopic and socially optimal groundwater management if the aquifer storage is relatively large. However, the bathtub model understates the magnitude and spatial nature of the groundwater externality which may mislead the policy implication (Brozović et al., 2010). To address this problem, Brozović et al. (2010) constructed a spatially explicit flow model to explore the economic impact of the groundwater externality. The research showed that the prediction of marginal pumping externality in spatially explicit model may be orders of magnitude more than the prediction in the bathtub model (Brozović et al., 2010). Meanwhile, Suter et al. (2012) also shows that there is less myopic behavior when the groundwater dynamics are governed by spatially explicit models. Therefore, the spatially explicit model is a more appropriate method used to simulate the hydraulic features in real world.

Recently, Mulligan et al. (2014) evaluated a tax policy and water user quota policy with a physical representation of the aquifer using a spatially explicit MODFLOW groundwater model. A novelty is that they conducted four scenarios to assess the efficiency of policy instruments for groundwater management. The social optimal allocation for groundwater, which maximizes the sum of all agent profits, represented the “upper-bound” for groundwater management policies; the unregulated farmer behavior indicated the “lower-bound” for groundwater management policies. The two policy scenarios are uniform tax and uniform quota on water use. In a tax policy scenario, they created a differentiated tax level ranging from \$2 to \$18 per 1000ft^3. Interestingly, this paper designed two tax scenarios: tax treatment without redistribution of tax revenue and tax treatment with the average yearly basin-wide tax revenue. The paper then compared the agents’ profits to explore the impact of tax redistribution on agents' profits. They collected some historical data about crop yield, crop irrigation requirements, and estimated data such as the farm operating cost and crop selling price. This paper also conducted an optimal control management formulation and solved it using Ground-water Management (GWM) software.

In contrast to the research of Mulligan et al. (2014), we consider how tax policies affect users' pumping behaviors by comparing the pumping path in a socially optimal scenario and the baseline. We aim to find if there are any different behaviors resulting from different tax policies on groundwater management and how the users evaluate these different tax policies. Figure 1 shows the research strategy in this study. We first focus on the social optimization. Numeric optimization was carried out by linking software of Modflow and MATLAB to derive a single intertemporal tax that incentivizes users to maximize the value of the aquifer, which is the "upper-bound" for groundwater management. Two kinds of tax policies are assessed in this study: tax instrument with threshold and tax instruments with two ways of tax revenue redistribution: side payment I and side payment II. The scenario without any policy interference is called "*Baseline*", in which groundwater users pump groundwater myopically from common pool to maximize their short term benefits. This scenario represents the "lower-bound" of groundwater management. A simulation is conducted in a spatially explicit model by using MODFLOW groundwater model. The z-Tree program is used to connect participants' decision and the aquifer change. In the real experiment, students from economics majors were recruited to the experiments and required to act as firm managers who make pumping decisions.

This paper contributes to the literature on the policy designs of the redistribution of tax revenue. Since the efficiency of a tax policy and participants' welfare depends crucially on the redistribution of tax revenues, this paper considers several modified tax policies, which lessen the distributional burdens to groundwater users. Another key contribution of this paper is to shed light on the groundwater users' opinions of the different policy instruments. These feedbacks are of vital importance for policy evaluation and adjustment. The rest of the thesis is organized as follows. We begin in Section 2 by introducing the groundwater simulation model, objective formulation, the way to identify the optimal social tax level and the hypothesis. Section 3 presents the details of results while Section 4 provides the discussion and conclusion.

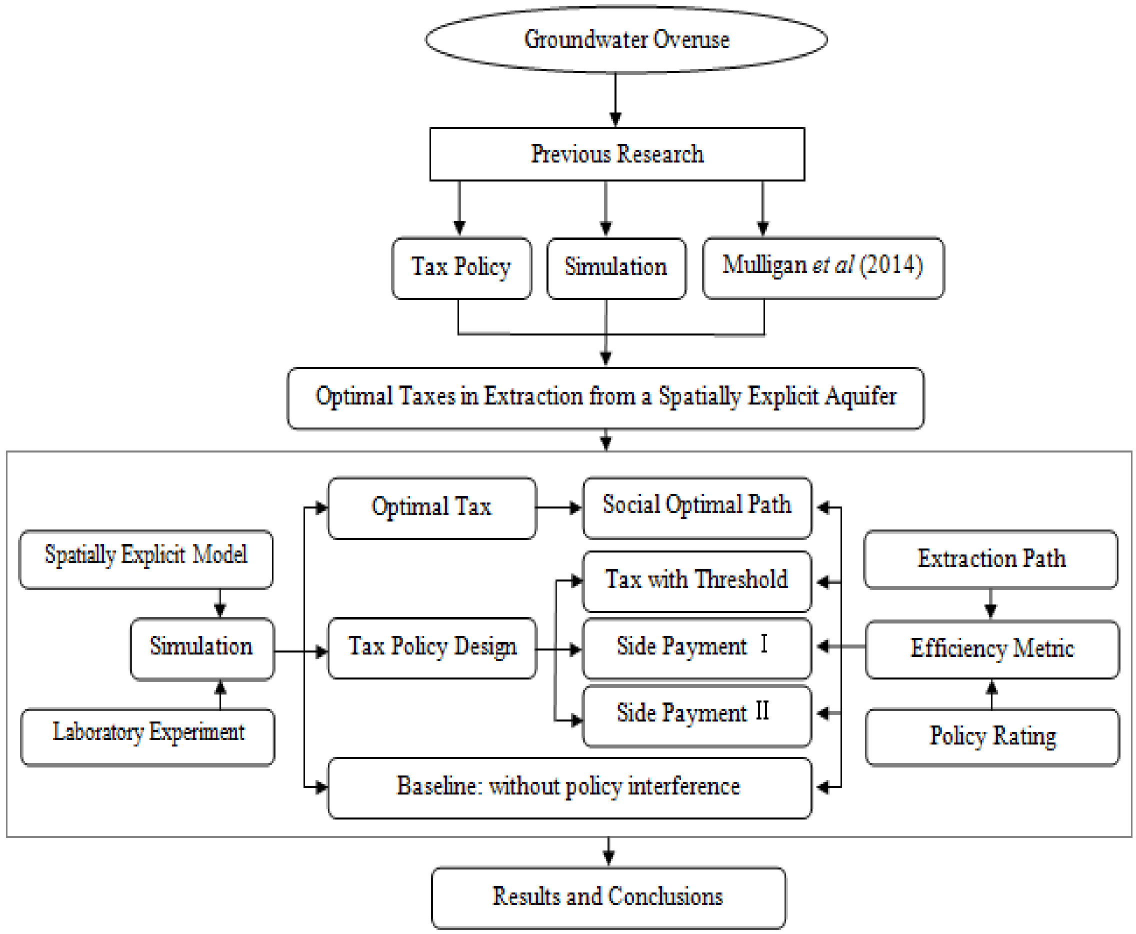


Figure 1 The research strategy

Chapter 2

METHODOLOGY

This section will describe the characteristics of simulation model, the way to identify the social optimal tax rate, the experimental design, and the hypotheses.

2.1 Groundwater Simulation Model

In this paper, the experiment is conducted based on a physics-based, spatially explicit aquifer, which was first reported in Li et al. (2014). There are four users who share a common aquifer in each group. All the groups start simultaneously and execute the program separately in MODFLOW and MATLAB. There is not any hydraulic relationship between groups. For each group, the wells are located in the middle of 1×10^6 m^2 plot and the group of four is located in a 2×2 grid which constitutes a $4\times10^6 m^2$ of surface area (see Figure 2). The well depth in any plot is determined not only by his/her own pumping decision but also by the adjacent exploitation from the users in their same group. The impact from other users' withdrawal will decrease with the distance from their wells increases. For example, the withdrawal from Firm 1 in Figure 2 has same impact on the well depth of Firm 2 and Firm 3, and a smaller impact on the Firm 4's depth.

To fulfill the purpose of this research, a few adjustments are implemented on Li et al. (2014)'s experiment design and programming. First, this research is conducted based on a confined aquifer, rather than two aquifers (an upper unconfined aquifer and a lower confined aquifer) in Li et al. (2014)'s experimental design. Second, there are no contamination scenarios in this experiment. Accordingly, the aquifer would never be contaminated in the given period and the risk information about contamination will not appear on z-Tree screen when participants make decisions. Third, this study only concerns the impact of tax policy instruments on the private decision. No public information, especially the extraction decision or water level information of other adjacent users are provided during the experiment. Beyond these changes, the hydrological characters and parameters used in this research are the same as the Li et al. (2014) spatially explicit model.

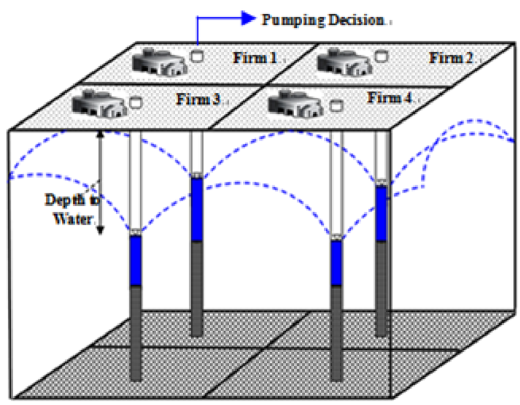


Figure 2 Example of 4 firms overlying a common groundwater aquifer in the spatially explicit experiment

2.2 Groundwater Management Formulation

Profits of firm manager in reality depend on a set of variables: crop categories, climate situation, labor supply, technology development, and irrigation demand, etc. Some of these variables are very complex to estimate or forecast because they vary over both time and space. Therefore, several simplifications are applied to focus on some most important variables. In this study, firm profits in a particular round are determined by the revenue and the cost of production. The revenue of production is the function of pumped quantity of groundwater. The cost is the function of both pumping rate and the depth to the water. The formulation of net benefits (*NB*) for agents in round *t* is:

$$NB_{it} = 360X_{it} - 2X_{it}^2 - 2X_{it}D_{it};\ \text{i} = 1,2,3,4;\ \text{t} = 0,1\ldots\text{n} \tag{1}$$

where NB_{it} is the abbreviation of net benefits at round t for user *i*; X_{it} is the pumping units at round *t* for user *i*; the part of $(360X_{it} - 2X_{it}^2)$ is the expression of revenue function of extraction. D_{it} is the depth of the water table below the land surface at time *t* for user *i*. The part of $2X_{it}D_{it}$ indicates the cost function of extraction. The net benefits function is concave, which means there always is a critical point of pumping rate to generate the global maximize of profits in each round.

Based on the individual profit function, each agent would make independent and arbitrary pumping decision to maximize their own profit in a given period. Thus, in the world of four participants, the total profit for the society from the management of groundwater in *t* round is shown below:

$$\text{Max} \sum_{t=0}^{n}\sum_{i=1}^{4}\beta_t(360X_{it} - 2X_{it}^2 - 2X_{it}D_{it});\ \text{i} = 1,2,3,4;\ \text{t} = 0,1\ldots\text{n} \tag{2}$$

where β_t is the per-period discount factor for round *t*.

2.3 Optimal Tax and Social Optimality

Without any policy intervention an aquifer user would act myopically and extract the water quantity to maximize their individual profit in each round. To maintain the efficient utilization of groundwater, a social planner is introduced in this experiment whose duty is to assess, execute, and monitor the tax policy. A tax incentivizes groundwater conservation. If tax revenue is not returned to the four groundwater users, it is not wasted. It is transferred. Thus, the management objective for the social planner is to transform the maximization of total profits of four users to maximize the net benefits of four groundwater users plus tax revenue. Accordingly, the optimal behavior represents the extraction strategies which maximize the net benefits plus tax revenue. However, different levels of tax rates can drive different social outputs. Suppose the social planner choose the optimal tax rate τ_{it} to maximize the total social benefits. With the incentive of tax policies, the groundwater users will select the "right" pumping rates (X_{it}^*) to maximize their own net benefits.

$$\begin{aligned} &\text{Max } NB_{it} \\ &= \text{Max } (360X_{it} - 2X_{it}^2 - 2X_{it}D_{it} - X_{it}\tau_{it});\ \text{i} = 1,2,3,4;\ \text{t} = 0,1\ldots50 \end{aligned} \tag{3}$$

Where τ_{it} is the tax rate for user *i* and *t* period and the $X_{it}\tau_{it}$ is the tax payment for user *i* in *t* period.

The first order condition for each period of equation (3) is:

$$NB_{it}{}'(X_{it}^*) = 360 - 4X_{it}{}^* - 2D_{it} - \tau_{it} = 0;\ \text{i} = 1,2,3,4;\ \text{t} = 0,1\ldots50 \tag{4}$$

$$X_{it}{}^* = 90 - \frac{D_{it}}{2} - \frac{\tau_{it}}{4};\ \text{i} = 1,2,3,4;\ \text{t} = 0,1\ldots50 \tag{5}$$

Replace the pumping rates (X_{it}^*) in Equation 2 using the first order condition of groundwater users (Equation 5). Then we have the social planner's objective function. The social planner's objective function:

$$\begin{aligned} &\text{Max} \sum_{t=0}^{\text{n}} \sum_{i=1}^{4} \beta_t (360X_{it} - 2X_{it}^2 - 2X_{it}D_{it});\ \text{i} = 1,2,3,4;\ \text{t} = 0,1\ldots\text{n} \\ &= \text{Max} \sum_{t=0}^{\text{n}} \sum_{i=1}^{4} \beta_t (360X_{it}^* - 2(X_{it}^*)^2 - 2X_{it}^*D_{it});\ \text{i} = 1,2,3,4;\ \text{t} = 0,1\ldots\text{n} \\ &= \text{Max} \sum_{t=0}^{\text{n}} \sum_{i=1}^{4} \beta_t [360 \cdot (90 - \frac{D_{it}}{2} - \frac{\tau_{it}}{4}) - 2 \cdot (90 - \frac{D_{it}}{2} - \frac{\tau_{it}}{4})^2 - 2 \cdot (90 - \frac{D_{it}}{2} - \frac{\tau_{it}}{4}) \cdot D_{it}]; \\ &\quad \text{i} = 1,2,3,4;\ \text{t} = 0,1\ldots\text{n} \end{aligned} \tag{6}$$

2.3.1 Simplifying Assumptions

The experiment has an explicit profit function, but the numerical groundwater model precludes analytical solutions to optimal behavior. This section presents simplifying assumptions that shrink the feasible set of solutions.

There are five actors in our experiments: four groundwater users (or firm managers) and a social planner. The social planner's problem is to set a tax that maximizes the total social discounted net benefits. The groundwater users choose different rate of extraction to maximize their current profits over an indefinite number of periods.

Determining the optimal choice profile X_{it}, where *i* indexes the groundwater user and *t* is the round number, is more difficult in a spatially explicit aquifer than one might expect. We start with a simplifying assumption about the range of choices:

(Assumption 1) Pumping choices takes on integer values and the feasible values range from 0 to 120.

This range is an artifact of the parameterization of the aquifer. Thus, there are 121^4 possible choice combinations in any period. Another simplifying assumption is that the infinite solution will be approximated. Because of significant discounting, overall social net benefits should be largely immune to dramatic changes after, say, period 50.

(Assumption 2) Period 50 reflects the end of the world.

A challenge is that the set of possible X_{it} remains too large. Even restricting to period 50, there are $(121^4)^{50}$ possible choice combinations, each leading to an observation on

NB. So, it would be prohibitively time-consuming to search with an algorithm running on top of the MODFLOW program for the maximum *NB*. The size of this problem leads us to further simplifying assumptions.

(Assumption 3) Contemporaneous symmetry.

We assume that the optimal solution will be contemporaneously symmetric, which is defined as every player must play the same pumping rate in any period *t*. Another reason for this assumption is that it will allow better communication to experiment participants; specifically, communicating an optimal asymmetric pumping rate, given that the profit functions are the same, would lead to distrust. This is similar to a pure strategy Nash Equilibrium. This assumption reduces the feasible set to $(121)^{50}$.

(Assumption 4) Intertemporal asymmetry.

We cannot make a similar intertemporal symmetry assumption for the following reasons. Groundwater pumping produces more profit in the present than in the future, so any socially optimal profile will have intertemporal asymmetry. This asymmetry will be unidirectional, meaning that pumping will decrease over time because profit is worth more today than tomorrow. One approach to solve this asymmetry is to use the Euler theorem, equating the net benefits of any given period. Unfortunately, the aquifer model involves recharge, accruing numerically and to any given well in a spatially asymmetric pattern. We think we would have to adjust this Euler formulation by recharge, but we cannot do this with theory. Thus, an alternate approach will be considered.

The above assumptions, collectively, indicate that the optimal strategy profile will be integers between 0 and 120, maximize discounted *NB* (plus tax, if applicable) at a time horizon of 50 periods, be contemporaneously symmetric, and be intertemporally asymmetric. Now, we use the intuition that, given the congestion externality, the only way to get users to pump below myopic rates is to impose a tax, which adjusts their marginal cost of pumping. Theoretically, this tax could be selected to drive users to the socially optimal profile.

Any optimal tax must be contemporaneously symmetric because of fairness and clarity in the experimental setting. Therefore, we also assume that the tax should be intertemporally symmetric.

(Assumption 5) Tax is fixed—intertemporally and contemporaneously symmetric.

The intuition is that though economists would ideally have taxes continuously change, most real world taxes (sales, gas, water, etc.) are fixed. We also believe it would be unnecessarily confusing for experiment participants to vary the tax in each period.

With the simplifying assumptions above, the first order condition of groundwater users is

$$X_t = 90 - \frac{D_t}{2} - \frac{\tau}{4};\ \mathrm{t} = 0,1\ldots 50; \quad (7)$$

The social planner's objective function will be:

$$\text{Max} \sum_{t=0}^{50} \beta_t \left[4 \cdot (360 \cdot (90 - \frac{D_t}{2} - \frac{\tau}{4}) - 2 \cdot (90 - \frac{D_t}{2} - \frac{\tau}{4})^2 - 2 \cdot (90 - \frac{D_t}{2} - \frac{\tau}{4}) \cdot D_t) \right]; \text{ t = 0,1…50}$$

$$= \text{Max} \sum_{t=0}^{50} \beta_t [2(180 - D_t)^2 - \frac{1}{2} \tau_t^2]; \text{ t = 0,1…50} \qquad (8)$$

Theoretically, the Equation (8) provides a potential solution for an optimal tax rates. However, it is not feasible because of the lack of information of depth (D_t). The depth in any well is determined by the pumping decisions and the recharge of the aquifer as well. The aquifer recharge in our spatially explicit model is much more complex than the one in single-aquifer model. However, we know that the depth in period one is 1 and has a range of 1 to 70 meter for the subsequent periods. Theoretically, the tax (τ) could have any nonnegative integer values. Equation (8), however, establishes a limit on tax because the value of extraction is also nonnegative integer, implying $\tau \in [0, 358]$ with $X_t \geq 0$. Therefore, with the range information of tax rate and well depth, we could capture the groundwater users' pumping rates under any combination of values in depth and tax rate, assuming that they would behavior rationally. For example, suppose that the tax per unit of extraction is 0 and the depth is 1 for the first round, the possible pumping rate to maximize their profit for the first round is approximate to 90 based on the Equation (8). Once participants submit their pumping decision, the Matlab would automatically calculate the depth of each groundwater users' well and the mobility of common aquifer as well, and then indicates the new well depth in each participants' screen through z-Tree. Again, with the Equation (8), one could know what the rational pumping rate for next round is with the tax rate of 0 and new depth information. Table 1 reports the possible rational pumping rates with all of the feasible values of tax rate and well depth. Specifically, the row of Table 1 indicates the tax per unit of extraction with the range of [0, 358] and the column represents the well depth for any single groundwater user, whose range is [1, 70]. The intersection of row and column will be the possible pumping rate by which groundwater users could obtain the maximum *NBs* in each period.

Table 1 The spreadsheet of finding optimal pumping rate

Depth \ Tax	0	1	2	3	…
1	90	89	89	89	…
1.1	89	89	89	89	…
1.2	89	89	89	89	…
1.3	89	89	89	89	…
1.4	89	89	89	89	…
…	…	…	…	…	…

Note: this table helps us to capture groundwater users' possible pumping rate with any combination values of depth and tax rate. The row indicates the tax per unit of extraction with the range of [0, 358] and the column represents the well depth for any single groundwater user, whose range is [1, 70]. The interaction value, for example 90, is the possible pumping rate when D=1 and τ =0 based on Equation (7).

2.3.2 Social Optimal

To find the optimal tax, a trial-and-error algorithm was used, where a simulation within the experiment was run with various taxes. For each tax, a *NB* for the four groundwater users over 50 periods was calculated. As part of this calculation, the total tax revenue was also recorded. The Table 2 and Figure 3 show the results of these experiments in table and graph.

Table 2 Identifying the optimal tax to maximize the total welfare

Tax	Discount Net Benefit					Tax Revenue	Total Social Benefits
	Firm 1	Firm 2	Firm 3	Firm 4	Total Users' Profits		
10	111,050.34①	111,056.52	111,056.52	111,058.65	444,222.02②	31,036.40③	475,258.42④
28	99,744.72	99,750.00	99,749.97	99,754.64	398,999.32	82,161.03	481,160.35
33	96,727.23	96,732.23	96,732.12	96,735.00	386,926.58	95,261.01	482,187.59
39	93,046.64	93,051.67	93,051.67	93,054.36	372,204.35	110,696.92	482,901.27
40	92,451.56	92,456.15	92,456.02	92,458.58	369,822.30	113,179.58	483,001.88
42	91,273.18	91,278.32	91,278.30	91,281.41	365,111.20	118,023.26	483,134.46
45	89,582.09	89,586.75	89,586.27	89,590.15	358,345.27	125,048.66	483,393.93
46	88,954.49	88,959.48	88,959.19	88,962.38	355,835.54	127,570.61	483,406.15
47	88,307.88	88,312.87	88,312.87	88,315.39	353,249.00	130,161.26	483,410.26
48	87,788.58	87,794.21	87,794.10	87,796.49	351,173.38	132,192.65	483,366.03
50	86,600.00	86,604.22	86,604.22	86,606.03	346,414.47	136,761.70	483,176.17
70	75,580.15	75,582.88	75,582.88	75,585.36	302,331.28	178,758.58	481,089.86
100	60,329.27	60,331.76	60,332.21	60,333.99	241,327.23	228,246.45	469,573.68
150	38,822.30	38,823.45	38,823.45	38,824.33	155,293.54	274,005.51	429,299.05

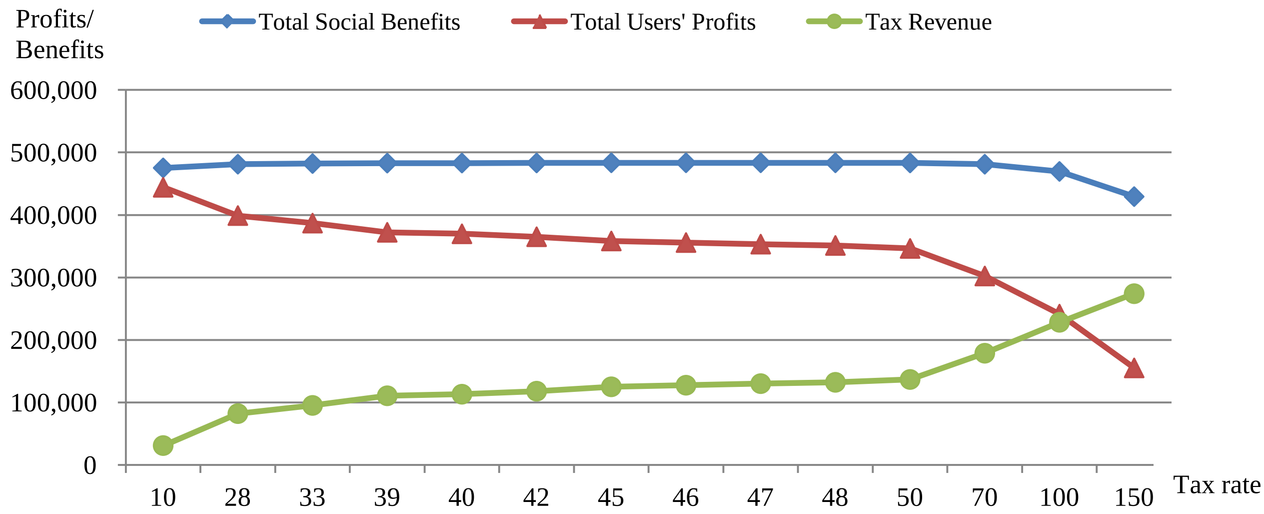
Note: ①The value of 111050.34 for user 1 with tax rate of 10 is aggregate *NB* based on the equation of $\sum_{t=0}^{50}\left[\left(\frac{1}{1+10\%}\right)^{t} NB_{1t}\right]$

② The value of 444222.02 with tax rate of 10 is aggregate of *NB* for 4 users. $\sum_{i=1}^{4}\sum_{t=0}^{50}\left[\left(\frac{1}{1+10\%}\right)^{t} NB_{it}\right]$

③The value of 31036.40 for 4 users with tax rate of 10 is aggregate tax revenue based on the equation of $\sum_{t=0}^{50}\left[\left(\frac{1}{1+10\%}\right)^{t}(4\cdot 10\cdot X_{t})\right]$

④The value of 475258.43 for 4 users with tax rate 10 is the summation of aggregate *NB* for 4 users and the aggregate tax revenue.

To find the optimal tax rate, a scatter plot graph is drawn with horizontal axis of tax rate and vertical axis of profits/revenue, which includes the total social benefits, total users' profits and tax revenue accrued to the social planner.



Note: The points of tax rates on the horizontal axis are selected randomly ranging from 0-358. The blue line represents the Total Social Benefits, which equals to the sum of total users' profits and tax revenue. The red line is the Total Users' Profits, which is the sum of net profits for four groundwater users. The green line represents Tax Revenue for four users.

Figure 3 The profits versus different tax rates

This simulation did not try every tax rate, but instead looked for a global optimum, assuming concavity of the total social benefits function. Figure 3 shows that the optimal tax is 47, at which point the sum of present value of the stream of production profits and tax revenue will be maximized. Another result is that, with the optimal tax of 47, the extraction path will be 78, 73, 69, 66, 64, 62, 61, 60, 60, 59, 59, and 58 in period 12 onwards and the pumping rates stay at the level of 58 for the rest of rounds. This pumping trajectory will be treated as the indicator of social optimal extraction, which will be used to compare the pumping rates under different tax treatments in the further steps.

2.4 Experimental Design

2.4.1 Tax Policy Designs

The social optimal extraction path will generate the sustainable groundwater management. With this "upper-bound" of groundwater management, we can assess how people behave under various tax policy instruments, explore whether any threshold levels or redistributions of tax revenue deliver greater efficiency, and compare the relative efficiency of different tax policy instruments with social optimal groundwater management.

In reality, the groundwater taxes are usually levied with a fixed tax rate or combine with threshold. For example, the groundwater tax rate is 20% of water value in Jakarta, Indonesia (FAO, 2004), whereas in Belgium, groundwater users will be taxed at progressive rates (European Commission, 2012). In this experiment, we simulate the reality by introducing two kinds of tax policy instruments: tax threshold and tax treatments with redistribution of tax revenue.

(1) Tax threshold policy

Tax threshold is defined as the level of pumping below which the participant will pay no tax. There are two tax thresholds in this experiment: low-level threshold and high-level threshold. The low-level threshold (hereafter referred to as Tax_0) is equivalent to a fixed tax, in which groundwater agents would be taxed if their pumping rates are above 0. The high-level threshold (hereafter referred to as Tax_50) represents the scenario that agents would be taxed if they pump more than 50 units. The thresholds apply throughout the game (all rounds with a game termination probability of 10%). But this will be changed for different games. Threshold levels were selected mostly ad hoc, but also to be below the sustainable behavior so that there was no anchoring.

(2) Tax treatments with redistribution of tax revenue

The second institution is an existing well owner side payment. This side payment might be warranted because we are moving from a presumptive rights regime to a tax regime. To make up for this, we offer a "confiscation" payment, which will be equivalent to the expected taxes paid if all owners were to play the optimal decisions for the expected game length of 10 rounds. Unlike other researches which redistribute tax revenue at end of each round or session, we provide this one-time payment at the very beginning of tax treatments. According to the different design ideas, there are two kinds of side payment: side payment I and side payment II.

Side payment I addresses the relationship between tax redistribution and the social optimal extraction. The key idea of the redistribution is that the groundwater users would not suffer welfare loss, if they exactly follow the social optimal pumping rates. More specifically, in the scenario of low-level tax threshold (hereafter referred to as *SP_0_30644*), groundwater agents would be taxed with the total amount of 30,644[1] in tokens in the first 10 rounds if they chose the social optimality as their pumping strategy. Similarly, the total amount of tax redistribution in high-level tax threshold (hereafter referred to as *SP_50_7144*) is 7144[2] in tokens.

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[1] The amount of redistribution of tax revenue in the scenario of low-level tax threshold for the first 10 rounds can be calculated as follows: 47×[(78-0)+(73-0)+(69-0)+(66-0)+ (64-0)+(62-0)+(61-0)+(60-0)+(60-0)+ (59-0)]= 30,644 tokens.

[2] The amount of redistribution in the high-level tax threshold case for the first 10 rounds can be calculated as follows: 47×[(78-50)+(73-50)+(69-50)+(66-50)+ (64-50)+(62-50)+(61-50)+(60-50)+(60-50)+ (59-50)]= 7,144 tokens.

Side payment II is designed based on the tax threshold level. In the low-level tax threshold (hereafter referred to as *SP_0_0*), no one time payment is warranted. This case is exactly same with the scenario of low-level tax threshold. In the scenario of high-level threshold (hereafter referred to as *SP_0_23500*), the side payment would be 23,500[3] in tokens.

Table 3 Tax treatments designs

Threshold level	Tax with Threshold (47/per unit paid on all pumping above threshold)	Side Payment (payment in beginning of $47 times optimal tax-response-pumping-rates above threshold) (47/per unit paid on all pumping above threshold)	Side payment (from 0 to threshold) (47/per unit paid on all pumping)
Low-level	***Tax_0***: Taxed at $47x_1^i$ for all i, there is no threshold	***SP_0_30644***: Taxed at $47x_1^i$ for all i and side payment is 30,644 tokens.	***SP_0_0***: Taxed at $47x_1^i$ for all i and there is no side payment
High-level	***Tax_50***: Taxed at $47(x_1^i – 50)$ for all i if $x_1^i > 47$, and 0 o.w.	***SP_50_7144***: Taxed at $47x_1^i$ for all i and side payment is 7,144 tokens.	***SP_0_23500***: Taxed at $47x_1^i$ for all i and side payment is 23,500 tokens.

Note: x_1^i is participant 1's pumping choice in round *i*. The policies are symmetric for all four participants.

2.4.2 Treatments Arrangement

To avoid participants' irrational pumping decision because of the anticipation for end of treatment, game length for each treatment will be randomly selected by using uniform distribution. The experiment starts from 5 rounds of practice to let participants to be familiar with the interfaces. There are two baselines with no policy interaction at the beginning and end of the formal experiment, with the purpose of comparing the users' extraction strategies after experiencing tax policy instruments.

[3] In Side payment II, the amount of redistribution in the high-level tax threshold case for the first 10 rounds can be calculated as follows: 47×50×10=23,500 tokens.

To avoid the "Learning Effect", there is a Latin squares shift among these different tax policies instruments (see Table 4).

Table 4 The order design of experiment

Session	Practice (5)	Treatment1 (10)	Treatment 2 (5)	Treatment 3 (12)	Treatment 4 (6)	Treatment 5 (9)	Treatment 6 (10)	Treatment 7 (12)	Treatment 8 (7)
1	P	*Baseline1*	*Tax_0*	*Tax_50*	*SP_0_30644*	*SP_50_7144*	*SP_0_0*	*SP_0_23500*	*Baseline2*
2	P	*Baseline1*	*Tax_50*	*Tax_0*	*SP_50_7144*	*SP_0_30644*	*SP_0_23500*	*SP_0_0*	*Baseline2*
3	P	*Baseline1*	*SP_0_30644*	*SP_50_7144*	*SP_0_0*	*SP_0_23500*	*Tax_0*	*Tax_50*	*Baseline2*
4	P	*Baseline1*	*SP_50_7144*	*SP_0_30644*	*SP_0_23500*	*SP_0_0*	*Tax_50*	*Tax_0*	*Baseline2*
5	P	*Baseline1*	*SP_0_0*	*SP_0_23500*	*Tax_0*	*Tax_50*	*SP_0_30644*	*SP_50_7144*	*Baseline2*
6	P	*Baseline1*	*SP_0_23500*	*SP_0_0*	*Tax_50*	*Tax_0*	*SP_50_7144*	*SP_0_30644*	*Baseline2*

Notes:
1. The number in parentheses refers to the game lengths or round number.
2. "P" refers to the Practice section; "*Tax_0*"refers to tax policy with 0 threshold; "*Tax_50*" refers to the tax policy with 50 thresholds; "*SP_0_30644*" refers to the tax treatment with side payment of 30644 and threshold of 0; "*SP_50_7144*" refers to the tax treatment with side payment of 7144 and threshold of 50; "*SP_0_0*" refers to the tax treatment with side payment of 0 and threshold of 0; "*SP_0_23500*" refers to the tax treatment with side payment of 23500 and threshold of 0.

2.5 Hypotheses

The purpose of this paper is to test the efficiency of tax policy in groundwater extraction reduction, compare the marginal incentive various tax policies instruments in groundwater extraction and address the groundwater users' opinions towards the different tax policies design. Based on these purposes, there are four principle hypotheses that need to be examined.

Hypothesis 1. Compared with the baseline, pumping rates in tax treatments will decrease significantly.

Hypothesis 2. The extraction choices do not change significantly in the two baselines, even though participants experience different tax policy instruments.

Hypothesis 3. All the tax policy instruments have the same marginal incentive for participants. Therefore, we expect no significant differences in withdrawal decisions among threshold treatments and up-front payment treatments.

Hypothesis 4. Participants' higher profits increase their favorability towards on the policies.

Table 5 Summary of hypothesis

	Description	Hypothesis test	Results
1	Do tax policy instruments **decrease** pumping rates?	$H_0: \text{Pump rates}^{\text{Baseline}} = \text{Pump rates}^{\text{tax policy}}$ $H_A: \text{Pump rates}^{\text{Baseline}} > \text{Pump rates}^{\text{tax policy}}$	Reject
2	Do pumping rates **decrease** in the second baseline after experiencing tax policy instruments?	$H_0: \text{Pump rates}^{\text{Baseline1}} = \text{Pump rates}^{\text{Baseline2}}$ $H_A: \text{Pump rates}^{\text{Baseline1}} > \text{Pump rates}^{\text{Baseline2}}$	Fail to Reject
3	Do pumping rates **change** in different tax policies?	$H_0: \text{Pump rates}^{\text{tax policy i}} = \text{Pump rates}^{\text{tax policy j}}$ $H_A: \text{Pump rates}^{\text{tax policy i}} \neq \text{Pump rates}^{\text{tax policy j}}$	Fail to Reject
4	Do participants rate the treatment a **higher** score if they earn more money?	$H_0: \text{Score}^{\text{high profits}} = \text{Score}^{\text{low profits}}$ $H_A: \text{Score}^{\text{high profits}} \neq \text{Score}^{\text{low profits}}$	Reject

Chapter 3

RESULTS

3.1 Experiment Description

The experimental sessions were conducted in May 2014 at the University of Delaware. 72 undergraduate students from economics majors were recruited to participate in the experiment. They were trained using a half-hour presentation and a few rounds of practice with exactly the same program and interface as the formal experiment. The operation interfaces were designed by z-Tree. The administrator of the experiment also provided printed instructions. There are two parts of instructions: general information and treatment information. The instruction of general information was provided before the presentation while the treatment instructions were provided separately at the beginning of each treatment.

There were six sessions in this experiment and each experiment session lasted approximately two hours. Participants earned approximately $30 based on their decisions and on the decisions of others sharing a common aquifer. Although the number of groups varies from one to three, depending on the available participants, in the real experiments, 12 participants (that is, three groups) took part in each session and 72 participants finished the experiment in total. There are 71 rounds in each session. Therefore, 72×71 individual choice combinations were collected in this experiment.

3.2 Differences in Pumping Rate and Depth across Treatments

3.2.1 Extraction Strategy in Different Scenarios

Figure 4 shows pumping rates in different treatments for each round, and Table 6 shows the t-test matrix for extraction strategies in different treatments. The figure shows that the pumping rates in both of the two baselines have the same trend with the myopic path. The downward shift of pumping rate baselines is apparent from myopic path. This is mainly because of the spatially explicit model design in our experiment. In the spatially explicit model, the depth to water is a function of the sequence of pumping rates in previous rounds and the distance with other players. The two baselines are ordered and arranged at beginning and end of the experiment. The results show that pumping rates in the two baselines seem to differ over time. The results of the t-tests show that the means of the two baselines are statistically the same. It shows that participants do not change their pumping strategy significantly in two baselines even though they had experienced different tax and up-front payment policies during the intervening rounds.

Compared with the baselines, the pumping rates in tax treatments reduced in each round and the paired t-test indicates that the decline is statistically significant. The implementation of the tax policy forces agents to incorporate the externality, and increases agents' pumping cost when making pumping decisions. This indicates that the tax instruments have significant potential to conserve groundwater. However, all of the pumping rates in the tax treatments fall below the optimal pumping path in most rounds. The systematic deviation from the optimal path indicates that the effect of tax policies tends to be slightly excessive. In addition, all of the pumping decisions in each round of tax policies are clustered, supporting the theoretical hypothesis that all tax treatments provided the same marginal incentive and participants recognized these incentives. The results indicate that most of the tax treatments have the same means of extraction strategies, which also support this conclusion.

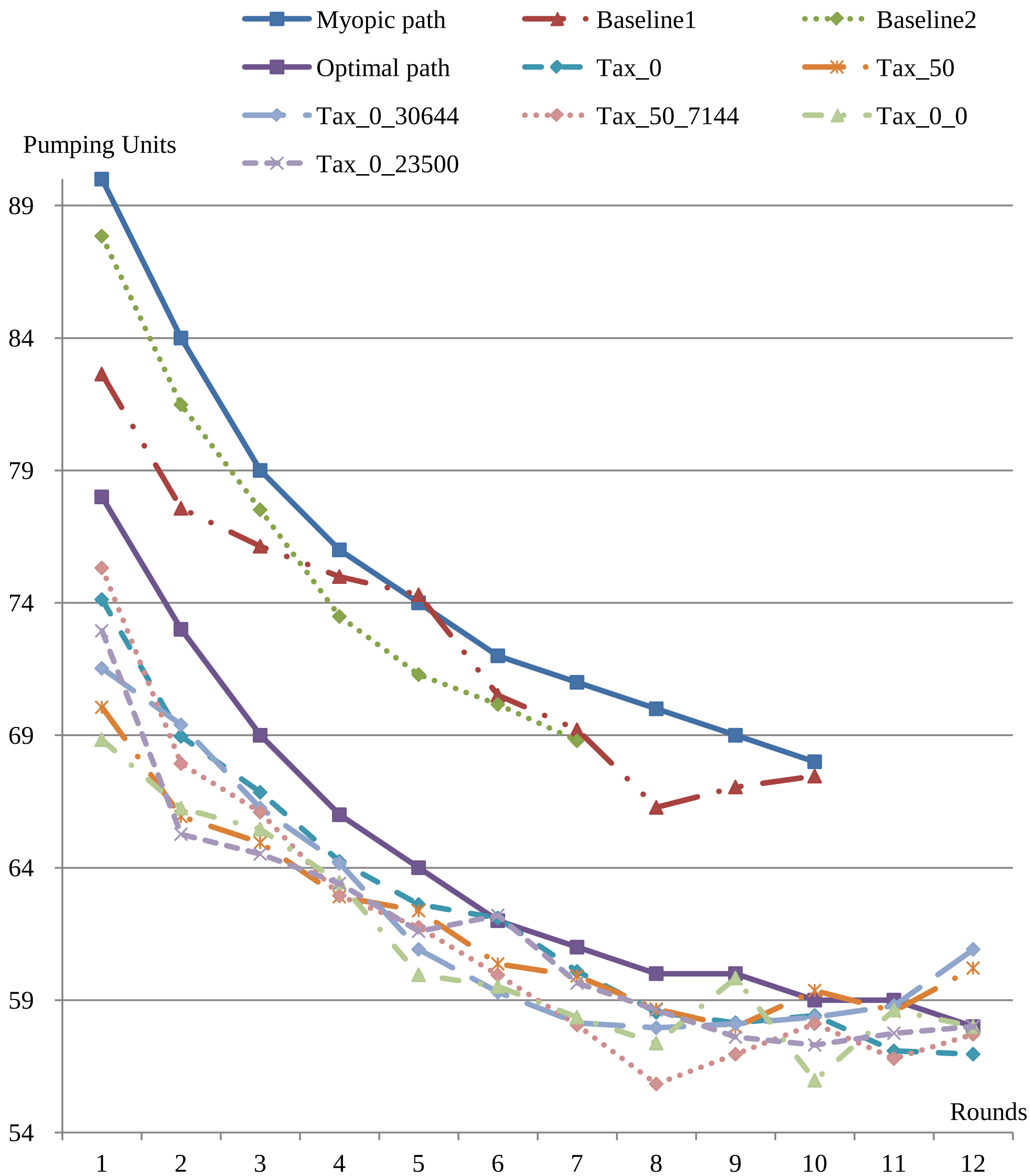

Figure 4 The pumping rate path in different treatments

Table 6 The t-test matrix for extraction strategies in different treatments

	Baseline1	*Baseline2*	*Tax_0*	*Tax_50*	*SP_0_30644*	*SP_50_7144*	*SP_0_0*	*SP_0_23500*	*Myopic*	*Optimal*
Baseline1										
Baseline2	0.5290									
Tax_0	<.0001	<.0001								
Tax_50	<.0001	<.0001	0.3470							
SP_0_30644	<.0001	<.0001	0.5270	0.6380						
SP_50_7144	<.0001	<.0001	0.0200	0.6330	0.3300					
SP_0_0	<.0001	<.0001	0.0390	0.0900	0.0380	0.5020				
SP_0_23500	<.0001	<.0001	0.0630	0.6340	0.4830	0.8200	0.2670			
Myopic	0.0080	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001		
Optimal	<.0001	<.0001	0.0004	0.0190	0.0080	<.0001	0.0020	0.0030	<.0001	

Note: The values in the table are p values.

3.2.2 Aquifer Depth in Different Treatments

Figure 5 indicates the depth change in each round in different treatments. The larger the pumping rate they choose, the faster the water table depletes. Hence, the results of aquifer depths indicate the same information as Figure 4 indicates. The depths in two baselines increase rapidly after three rounds and then the depth gap between baselines and tax treatments become progressively larger. Depths in tax treatments are clustered together and lie below the depth of social optimal extraction. This is consistent with the results of extraction change: the pumping rates in tax treatments are smaller than the social optimal extraction in each round and therefore the groundwater depletion in tax treatments will be much slower.

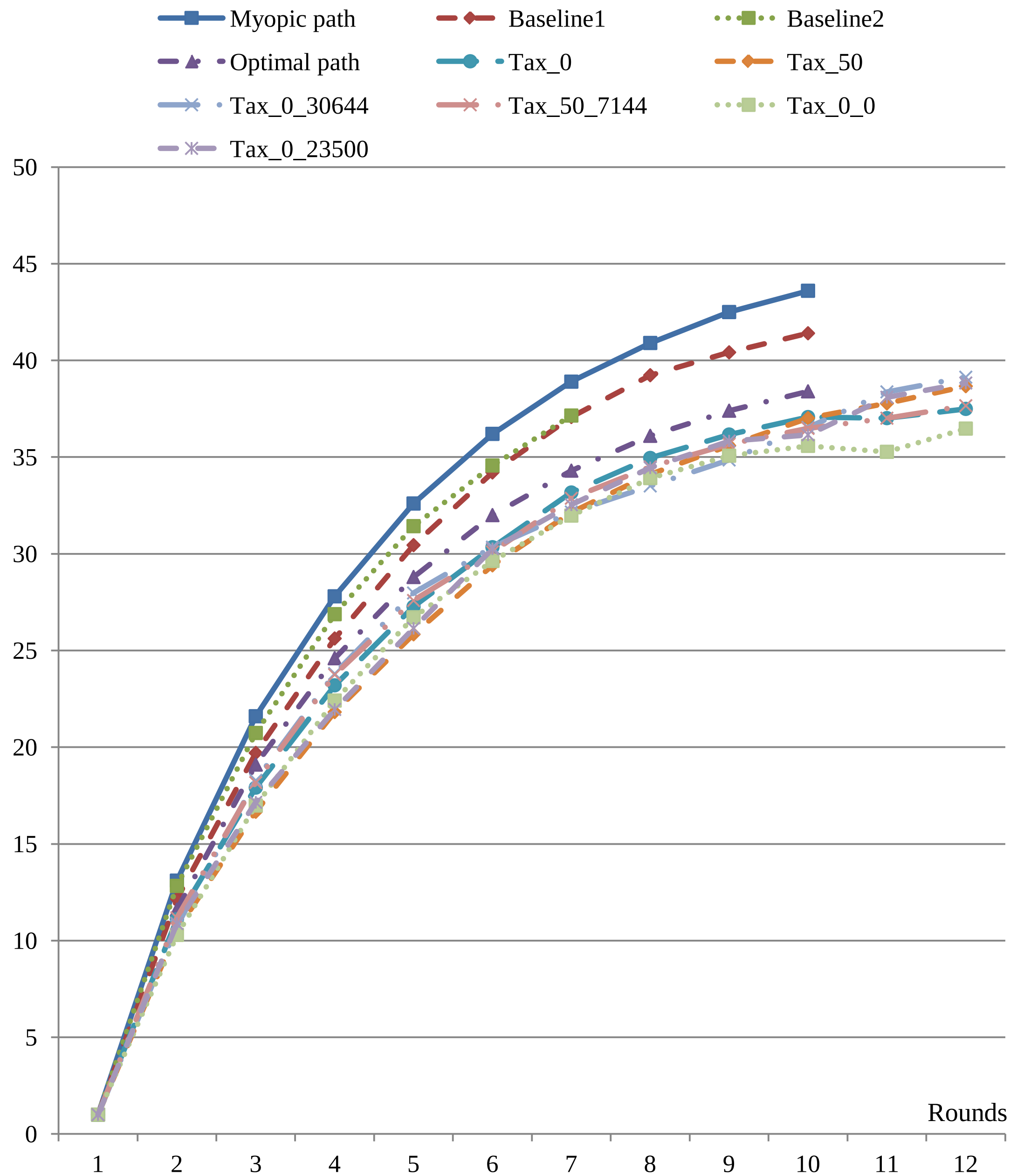

Figure 5 The depth path in different treatments

3.3 Analysis of Extraction Profit

Although tax policies could drive the pumping rates down from the free-access scenarios, the policies could still fail if groundwater users suffer heavy tax burdens. This part mainly focuses about the issues of welfare analysis. Before that, it is necessary to establish an image of the profit table. There are 6 sections and each section consist of 12 participates. The total sample size is 72. There are 8 treatments in each section: (1) *Baseline1*; (2) *Tax_0*; (3) *Tax_50*; (4) S*P_0_30644*; (5) *SP_50_7144*; (6) *SP_0_0*; (7) *SP_0_23500*; (8) *Baseline2*. The important thing to note here is that, for each treatment, the round number varies in each different section, ranging from 5 to 12 (see Table 4). Thus, the profit dataset is composed of 72×71 (71 is the total round number) cells with a lot of blanks because some treatments did not last 12 rounds.

We calculate the average profit based on the number of participants by summing the profits in each round up and dividing them by the number of participants. For the first five rounds, there are no blanks. Thus the denominator is 72, which is the total participant number. For the remaining rounds, from 6th round to 12th round, however, the denominators may be 48, 24 or 12 because of the variation of round number design (see Table 4). In this way, we can get the average profit per participant for each treatment. Since there are no blanks in the first five rounds, we report the profit table just for the first five rounds (see the Table 7).

Table 7 The average profit in the first five rounds (without side payment)

Treatment	1	2	3	4	5
Baseline1	14,814.06	13,015.40	12,026.51	11,270.33	10,602.32
Tax_0	11,657.10	10,210.36	9,330.13	8,799.99	8,197.06
Tax_50	13,824.85	12,469.63	11,787.66	11,109.61	10,750.72
SP_0_30644	11,096.88	10,164.79	9,214.52	8,326.74	8,122.12
SP_50_7144	13,758.85	12,473.78	11,541.65	10,701.53	10,527.44
SP_0_0	11,257.51	10,198.32	9,415.81	8,703.67	8,076.16
SP_0_23500	11,295.21	9,901.58	9,307.15	8,786.14	8,200.83
Baseline2	15,681.89	13,666.36	12,404.93	11,540.55	10,906.79
Myopic case	16,020.00	13,926.00	12,549.00	11,575.00	10,865.00
Social optimal case	12,090.00	10,505.00	9,449.00	8,696.00	8,153.00

Another complication is the best way to add the one-time side payment to each round. There are three treatments with side payments: *SP_0_30644*, *SP_50_7144* and *SP_0_23500*. Although the one-time side payments were provided at the beginning of the three treatments, they would be divided to each round to generate the nominal profits for each round. Since we calculated the total side payment based on 10 rounds in the experiment design stage (see Table 3), one way to split the one-time payment is to divide the side payment by 10. Take the tax treatment with side payment of 30,644 tokens for example. The side payment to rebate for the first round is 3064.4 tokens (equals to 30644/10) with 10 rounds to split the one-time side payment. Side payment in the rest round would be the value that the average side payment (3064.4 tokens) times the corresponding discount factor so that the real values of side payment in each round would be same in the first round. More specifically, the nominal side payment in the 2nd round is 3370.84 tokens (=3404.89$\times$1.1). Table 8 shows the nominal values of side payments in each round.

Table 8 The nominal values of side payments in different rounds

Treatment	Discount factor	1	1.1	1.21	1.33	1.46	1.61	1.77	1.95	2.14	2.36
	side payment \round	1	2	3	4	5	6	7	8	9	10
SP_0_30644	30,644	3,064.40	3,370.84	3,707.92	4,075.65	4,474.02	4,933.68	5,423.99	5,975.58	6,557.82	7,225.69
SP_50_7144	7,144	714.40	785.84	864.42	950.15	1,043.02	1,150.18	1,264.49	1,393.08	1,528.82	1,684.52
SP_0_23500	23,500	2,350.00	2,585.00	2,843.50	3,125.50	3,431.00	3,783.50	4,159.50	4,582.50	5,029.00	5,541.18

For the tax treatments with redistribution, the nominal values of side payment in table 8 would be added to the corresponding treatment's profit table in table 7 (but only for five rounds). Table 9 indicates the profit table with side payment and Figure 6 shows the graph of profit change in first five rounds.

Table 9 The average profit in the first five rounds (with side payment)

Treatment	1	2	3	4	5
Baseline1	14814.06	13015.40	12026.51	11270.33	10602.32
Tax_0	11657.10	10210.36	9330.13	8799.99	8197.06
Tax_50	13824.85	12469.63	11787.66	11109.61	10750.72
SP_0_30644	14161.28	13535.63	12922.44	12402.39	12596.14
SP_50_7144	14473.25	13259.62	12406.07	11651.68	11570.46
SP_0_0	11257.51	10198.32	9415.81	8703.67	8076.16
SP_0_23500	13645.21	12486.58	12150.65	11911.64	11631.83
Baseline2	15681.89	13666.36	12404.93	11540.55	10906.79
Myopic case	16020.00	13926.00	12549.00	11575.00	10865.00
Social optimal (without rebate)	12090.00	10505.00	9449.00	8696.00	8153.00
Social optimal (rebate)	15494.89	14250.38	13568.92	13224.50	13124.14

Note: the profit values in this table are generated by combining table 7, table 8 and table 9. For the treatment without side payment, the profits values in this table are exactly same with table 7.

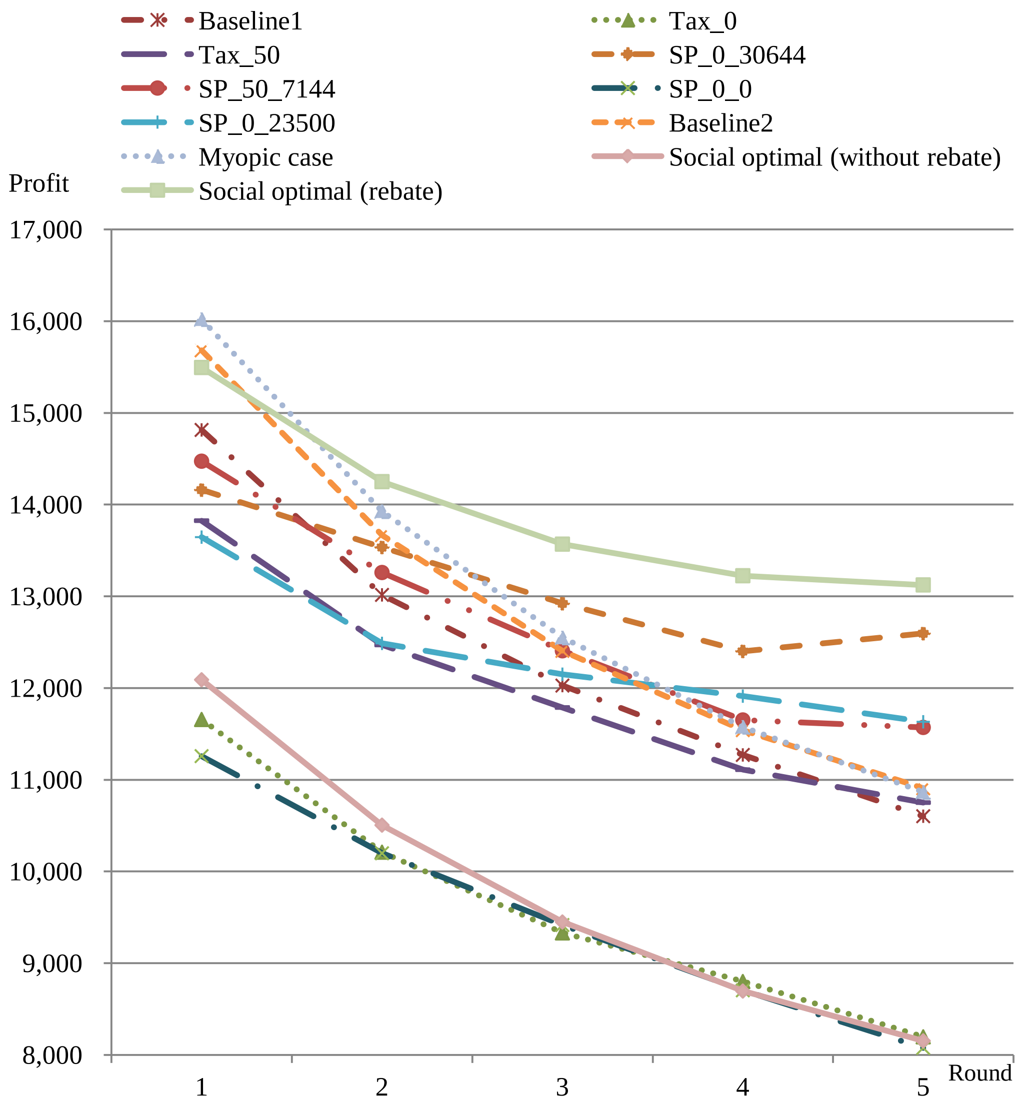

Figure 6 The average profit in the first five rounds (with partial side payment)

Figure 6 shows that participants' welfare levels crucially depend on the redistribution of tax revenues. The profit paths for tax treatments with distribution are higher than the baselines as well as the tax treatment without distribution. Besides, the higher side payments are, the closer of the profit paths to the social optimal scenario. The figure indicates that participants' profits would be significantly reduced in the treatments without redistribution of the tax revenue for each round. There are great profits gaps between baselines or tax treatments with redistribution and tax treatments without redistribution. The level of threshold determines the profits level. We can see that profits in Tax_50 are greater than the profit in Tax_0. The profits for tax treatments of redistribution and baselines, as well as the myopic case are clustered together, which suggests indifference among the outcomes. These results meet the expectation of the experiment, which indicates the efficiency of tax policies with redistribution in lessening the tax burdens on users.

Combined with the figure of extraction strategies, these figures show that the tax policies reduce the pumping rates and maintain the profit level with the unregulated situation. The profit figure also indicates the differences between social optimum and other treatments. For most of treatments, except for the tax treatment with 30,644 side payment, the profit difference between social optimum and tax treatments are increasing over time. In sum, the tax policies with redistribution of tax revenue are recommended to correct the overuse of groundwater because they reduce the pumping rate and keep the users' welfare level as the unregulated cases.

3.4 Assessment of Tax Policy

Participants' opinion of the treatment is another important criterion in assessing the efficiency of the different policy instruments. In this experiment, participants rated the different tax policy instruments from three aspects: beneficial to individual, beneficial to group, and fairness at the conclusion of the session. Table 10 shows the results of the opinion survey. The values of the means are the results based on 72 samples.

The results show that on average, the *Baseline* has the highest scores in the three questions. More specifically, the *Baseline* was the most beneficial to an individual and group and the fairest policy among all the policy instrument designs. Except for the *Baseline*, participants tend to give higher scores to those treatments from which they get more side payment. For the aspects of beneficial to individual and beneficial to group, the average ratings means of tax treatments with a 30,644 side payment is higher than the ratings of tax treatment with a 23,500 side payment, and then this is followed by the tax treatment with a 7,144 side payment. Participants also rated the tax treatment with a high threshold higher than the tax treatment with a low threshold. For the aspect of fairness, the average means of *SP_0_30644* is higher than the values of *Tax_50*, and then followed by the treatment of *SP_50_7144*, and the treatment of *SP_0_23500*. In sum, participants' opinions on the treatments do not always match their received welfare. Participants tended to rate the tax treatments very low, even in some cases when they made more profits than the baseline.

Table 10 The statistical description of opinion survey

	Baseline	*Tax_0*	*Tax_50*	*Tax_0_30644*	*Tax_50_7144*	*Tax_0_0*	*Tax_0_23500*
How beneficial was the policy	7.76	4.33	5.49	7.29	6.31	4.04	6.54
to you as an individual?	(2.30)	(2.36)	(2.01)	(2.05)	(1.92)	(2.15)	(2.28)
How beneficial was the policy	6.60	5.06	5.90	6.57	6.10	4.65	6.19
to the group as a whole?	(2.46)	(2.50)	(2.16)	(1.98)	(1.91)	(2.29)	(2.15)
How would you rate the	7.33	5.64	6.76	6.79	6.68	4.82	6.36
fairness of the policy?	(2.55)	(2.64)	(2.27)	(2.35)	(2.39)	(2.55)	(2.43)

Note: since the conditions for the two baselines are exact same, we combine the baseline together and name it as "*Baseline*". The rates for each treatment are the average based on the sample size of 72; The number in parentheses refers to the standard deviation.

3.5 The Relationship between Profit and Rank

Although participants rank the different treatments with different scores, an important question is: whether or not there is any relationship between how much they earn from a treatment and how they rank that treatment. This section of the paper will show the relationship between the average profits and average scores in different sessions.

Calculating the arithmetic mean profit per treatment and opinion scores per participants is simple, but it could be misleading. The complication involves how to split the one-time side payment to each round. The reason that we do not adopt the same method in 3.3 is that participants' opinions were based on what they earn and how many rounds they experienced. For example, in session 1, there are six rounds in *SP_0_30644*. Participants rank this treatment based on their profits in each round of six plus the side payment of 30,644 tokens in terms of six rounds. The round number of *SP_0_30644* in session 2 is nine. Thus their opinion scores are provided based on their profits in nine rounds plus the side payment of 30,644 tokens in terms of nine rounds. In all, participants' opinion scores are greatly affected by the round number and how the one-time side payments are arranged in the given number of rounds. Due to the different number of rounds in different sessions, the one-time side payments are split into n parts in which n is equal to the round number, and then multiplied by the corresponding discount factor to generate a nominal side payment for each round. Adding the nominal side payment for each round to the profit in that round, we could get the new profit table for treatments with side payments.

The average per round profits for each session is calculated by averaging the profits for each participant and then averaging the profits for each round. The average rates for each session are calculated by averaging the 12 participants' rates for each treatment. There are also the overage average rates for each treatment, which are based on the 72 samples. For each treatment, there are three aspects of rates and an average per round profit (see Table 11).

Table 11 The average rates per sessions and the average per round profits

Treatment		Session1	Session2	Session3	Session4	Session5	Session6	Average
Baseline	Beneficial to individual	7.75	7.50	7.75	8.17	6.83	8.58	7.76
	Beneficial to group	6.75	7.25	7.00	6.67	5.42	6.50	6.60
	Fairness of the policy	8.17	7.08	7.75	7.58	5.92	7.50	7.33
	Average per round profits	11745.41	11666.53	11092.32	11566.36	11777.75	11479.08	11554.57
Tax_0	Beneficial to individual	3.50	3.58	4.92	4.25	4.33	5.42	4.33
	Beneficial to group	4.25	4.17	5.17	4.67	5.50	6.58	5.06
	Fairness of the policy	5.58	6.58	6.00	4.75	5.25	5.67	5.64
	Average per round profits	9704.28	8313.53	8324.67	8316.73	9459.98	8381.40	8750.10
Tax_50	Beneficial to individual	5.42	5.00	6.50	5.58	6.25	6.67	5.90
	Beneficial to group	4.50	4.92	5.92	5.08	5.42	7.08	5.49
	Fairness of the policy	6.50	6.58	7.92	6.58	6.00	7.00	6.76
	Average per round profits	10601.54	11811.54	10647.98	10976.12	11151.61	11584.03	11128.80
SP_0_30644	Beneficial to individual	7.17	7.75	7.08	7.25	7.33	7.17	7.29
	Beneficial to group	6.33	6.92	6.33	6.67	6.83	6.33	6.57
	Fairness of the policy	6.58	7.25	7.00	6.92	6.67	6.33	6.79
	Average per round profits	15944.50	13902.45	16128.80	12597.77	13489.80	12591.44	14109.13
SP_50_7144	Beneficial to individual	6.08	6.75	5.92	6.17	6.00	6.92	6.31
	Beneficial to group	5.92	6.92	5.75	5.83	6.25	5.92	6.10
	Fairness of the policy	6.17	7.00	7.08	6.25	6.33	7.25	6.68
	Average per round profits	12304.45	13352.61	11263.27	13357.89	11823.34	11654.78	12292.72
SP_0_0	Beneficial to individual	3.75	3.50	4.17	3.75	4.58	4.50	4.04
	Beneficial to group	4.08	4.17	4.75	4.00	5.17	5.75	4.65
	Fairness of the policy	5.58	4.75	5.25	3.75	4.92	4.67	4.82
	Average per round profits	8583.69	8409.96	9031.23	8708.98	9769.56	7886.68	8731.68
SP_0_23500	Beneficial to individual	6.25	6.67	6.50	6.25	6.83	6.75	6.54
	Beneficial to group	5.83	5.50	6.17	6.17	6.83	6.67	6.19
	Fairness of the policy	6.83	7.08	6.83	5.92	6.67	4.83	6.36
	Average per round profits	11760.63	12434.34	12451.18	14323.44	11814.46	14361.69	12857.62

Note: For each treatment, participants rated the different tax policy instruments from three aspects: beneficial to individual, beneficial to group and the fairness of the policy. The rates under each session are averaged based on 12 participants, while the overall average in the last column are based on the total sample of 72. For each session, the averages per round profits are presents in the last row.

We then draw three scatter diagrams which indicate the relationship between profits and each of three aspects of rates. Although there are six sessions, we just focus on the overall average of profits and rates (the last column in Table 11).

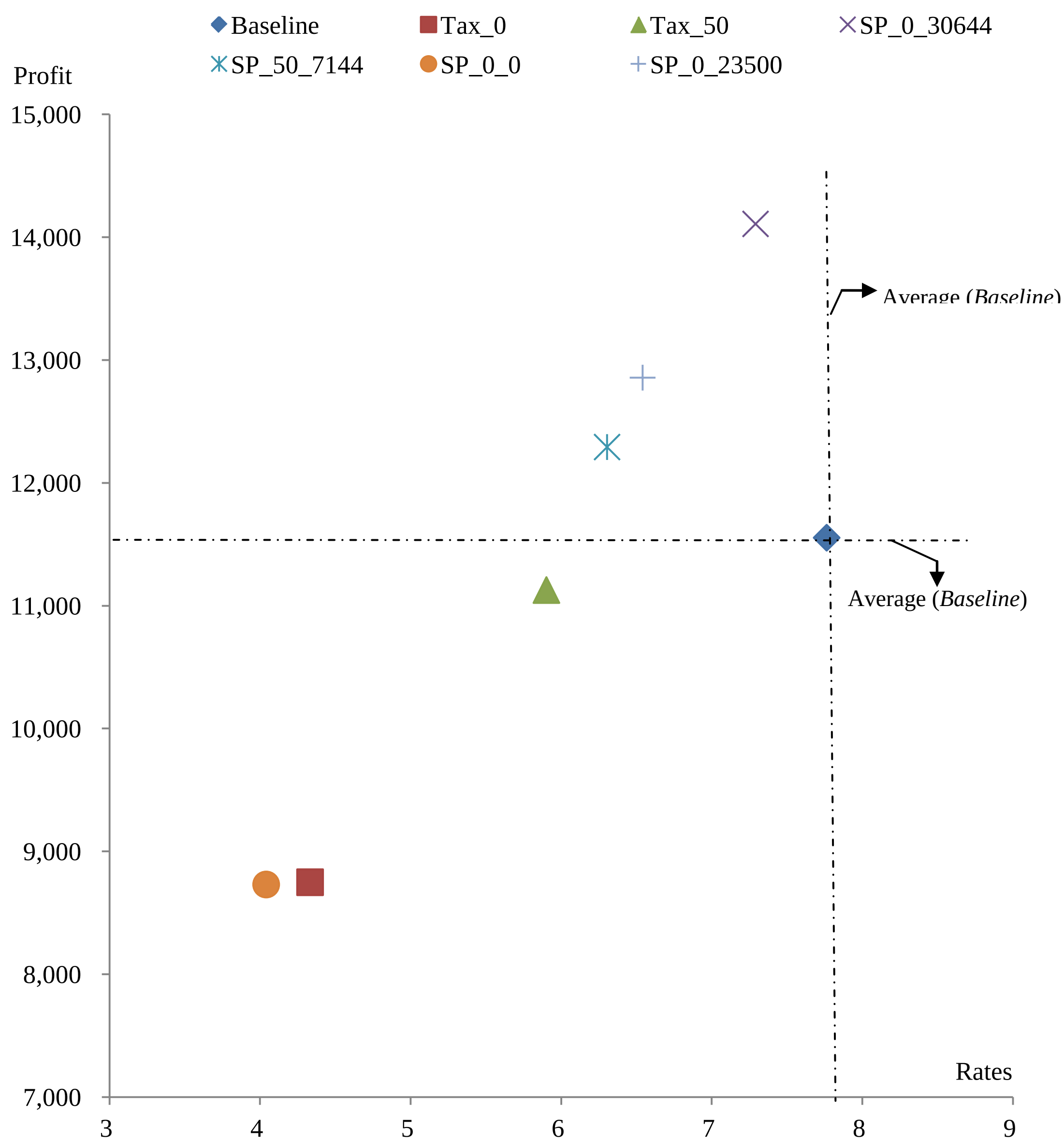

Figure 7 The average rates on beneficial to individual and average per round profits

Each scatter represents the overall average rate and the average per round profits for a certain treatment. The dashed line indicates the mean values of rate and the average per round profits for Baseline in all sessions, which constructs a benchmark to evaluate the relationship between rates and profits in tax treatments.

The scatter plots in Figure 7 above indicate the relationship of rates and average per round profits in two-dimensions. The horizontal axis is the opinion scores of beneficial to the individual with a range of 1 to 10 and the vertical axis is the average per-round profit in tokens. The different shape of scatters represents the different observations of rates and average per round profits for different treatments.

The two-dimensional region is divided into four parts by two dashed lines which represent the mean values of rates and average per round profits in all sessions in *Baseline*. Surprisingly, participants' opinions on the treatments did not always match their received welfare. Figure 7 indicates that the overall average rates and profits of *SP_0_30644*, *SP_50_7144* and *SP_0_23500* locate in the upper-left area, which means the higher profits and lower rates, compared with the *Baseline*. More specially, participants rate the tax treatments with side payments lower than the baseline. This result indicates that the baseline appears to be more beneficial to individual than the three tax treatments with side payments, although profits in these three treatments are higher than the profits in baseline. The plots of tax treatments without side payments like *Tax_0*, *Tax_50* and *SP_0_0* locate in the lower-left area, which indicates the lower profits and lowers opinions, compared with the *Baseline*. Specially, the tax treatments without side payments have lower rates and lower profits. Besides, the high threshold level generates higher profits as well as higher rates than the low level of threshold. This indicates that high threshold level is more profitable and more beneficial to individual than low threshold level.

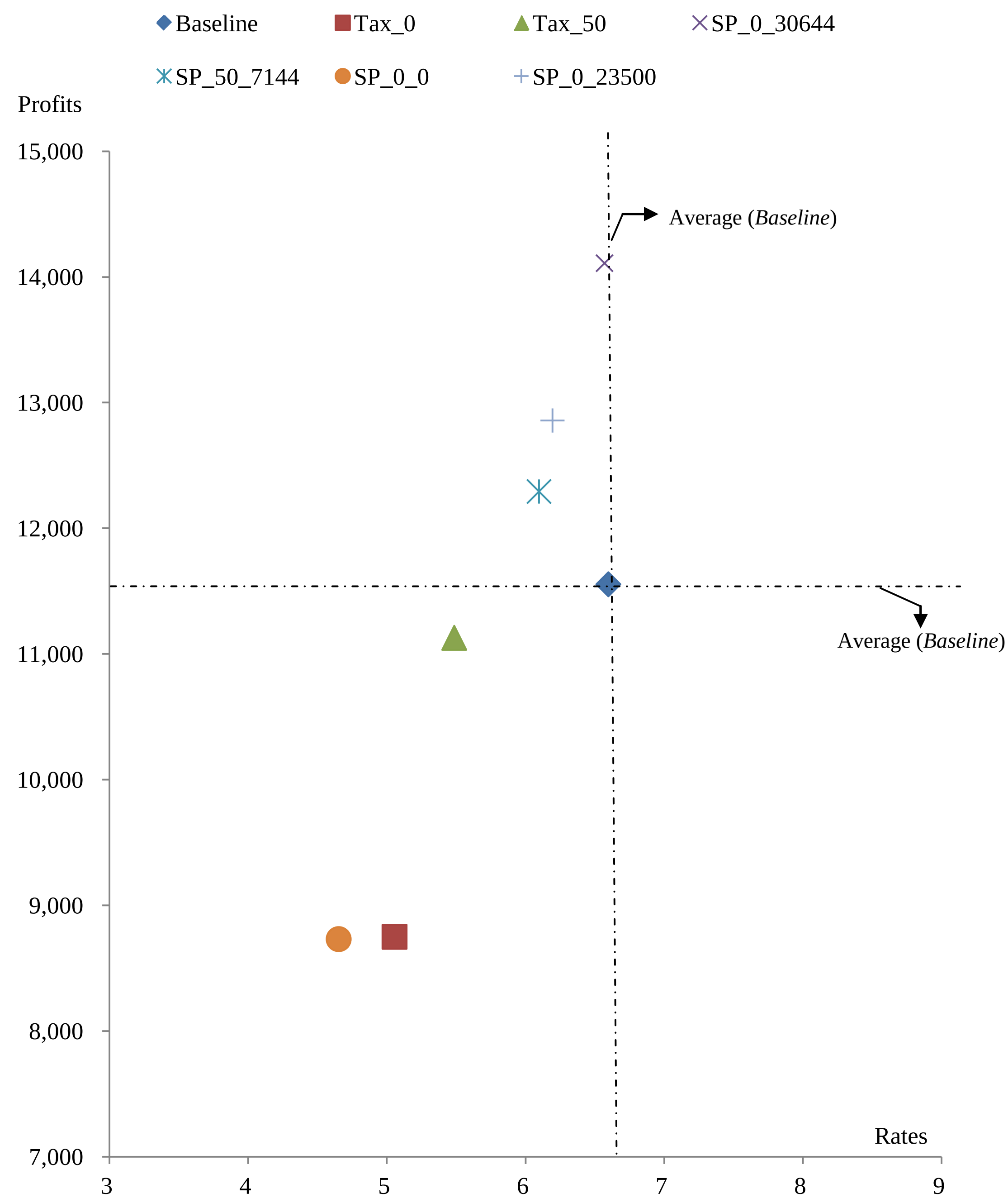

Figure 8 The average rates on beneficial to group and average per round profits. The charateristics as well as the explanation of scatters in this figure are same with Figure 7.

Figure 8 shows the average participants' rates on beneficial to group and the average per round profits. The Figure 8 has same coordinate axis as well as the scatters and dashed line with Figure 7. Compared with the Baseline, the treatments with side payment like *SP_0_30644*, *SP_50_7144* and *SP_0_23500* have higher average per round profits but less beneficial to group, whereas the treatments without side payment like *Tax_0*, *Tax_50* and *SP_0_0* have lower rates and lower average per round profits. Different with Figure 7, the rates of tax treatments with redistribution are much close to the rates of *Baseline*. Especially, the treatment of *SP_0_30644* almost has the same rate with the *Baseline*. Table 11 also indicates that there aresix sessions from the treatments with side payments locates the upper-right region. That means, for some sessions in treatments with side payment, participants earned higher profits and rate higher on beneficial to group than the *Baseline*. The number of scatters in the upper-right region also indicates that the larger amount of side payment, the higher probability that the scatters locate in this region, as we can see that there are three scatters from *SP_0_30644*, two from *SP_0_23500* and only one from *SP_50_7144*. Participants are more likely rate the tax policy with side payment higher in term of beneficial to group than baseline once they earned higher profits.

Besides, we can see that participants' rates on beneficial to group are generally higher than the rates on beneficial to individual for those tax treatments without side payment. Probably, participants believe that tax treatments without redistribution are more beneficial to the group rather than the individual.

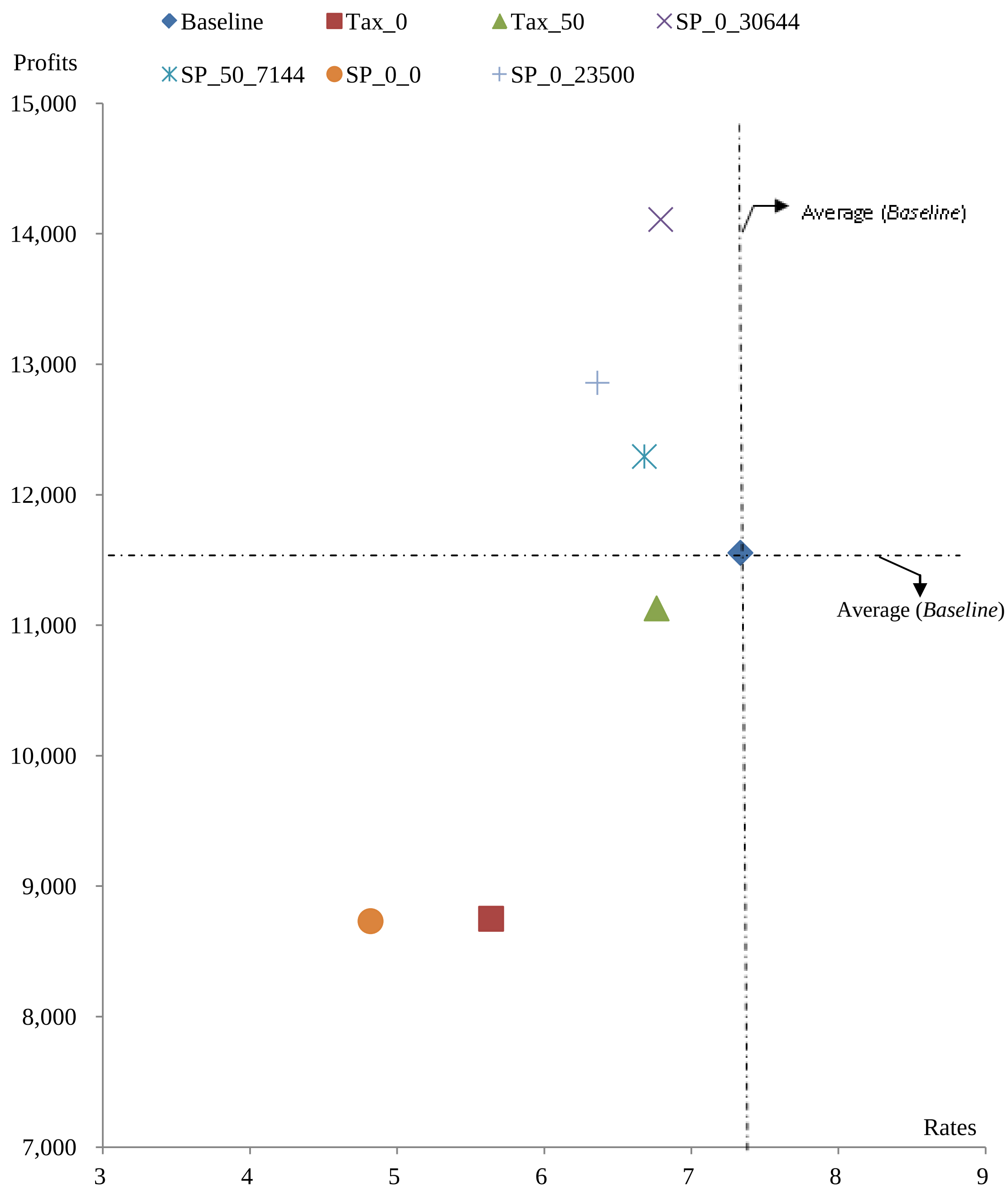

Figure 9 The average rates on fairness and average per round profits

Figure 9 shows the relationship between average participants' rates on fairness of the policy and the average per round profits. The Figure 9 has same instruction for coordinate axis as well as the scatters and dashed line with Figure 7 and Figure 8. Participants insisted that *Baseline* is the fairest policy design even though the averages per round profits in *Baseline* are smaller than the tax treatments with side payments a. The treatments without side payment are not as fair and profitable as *Baseline*. Different with Figure 7 and Figure 8, participants increased their rate on fairness for treatment with high threshed like *Tax _50* and *SP_50_7144*. Similarly, the rates for tax treatments like *Tax_0* and *SP_0_0* also increased than the rates in Figure 7 and Figure 8. This indicates that the tax treatments without side payment or low side payment like *SP_50_7144* play more important roles in ensuring fairness rather than in benefiting individuals or groups.

In sum, the descriptive statistics show that participants' rates on the different tax policies did not always match their received welfare. There are only few sessions involving the rate on beneficial to group in which tax treatments with side payments have higher profits and higher rates than baseline. Beyond that, however, participants insist that baseline is more beneficial to individual as well as to group and fairer than all of tax treatments, especially the tax treatments with side payments. A potential explanation is that groundwater users reject policy intervention such as tax policies. Profits and rates in tax treatments with side payments are generally higher than the tax treatments without side payments. The treatments without side payments are more important in ensuring fairness rather than beneficial to individual or group.

3.6 The Regression of opinions

The graphs and tables above indicate the relationship between participants' profits and their ratings about the tax treatments. To explore the exact impact of participants' profits on their rate, we construct a regression. The dependent variables are the three opinion scores, which will be estimated separately in three models. The independent variables are profits, round number, and the dummy variables of treatments. The theoretical models are the following:

$$\text{Opinion}_{\text{individual}} = \alpha_{10} + \alpha_{11} \cdot \text{Profits} + \alpha_{12} \cdot \text{Round} + \alpha_{13} \cdot \text{Treatment} + \alpha_{14} \cdot \text{Treatment} \times \text{Profits} + \varepsilon_{11};$$

$$\text{Opinion}_{\text{group}} = \alpha_{20} + \alpha_{21} \cdot \text{Profits} + \alpha_{22} \cdot \text{Round} + \alpha_{23} \cdot \text{Treatment} + \alpha_{24} \cdot \text{Treatment} \times \text{Profits} + \varepsilon_{22};$$

$$\text{Opinion}_{\text{fairness}} = \alpha_{30} + \alpha_{31} \cdot \text{Profits} + \alpha_{32} \cdot \text{Round} + \alpha_{33} \cdot \text{Treatment} + \alpha_{34} \cdot \text{Treatment} \times \text{Profits} + \varepsilon_{33};$$

where $Opinion_{individual}$ indicates the rate of benefit to individual, $Opinion_{group}$ is the rate of benefit to the group and the $Opinion_{fairness}$ is the fairness of the given tax treatment. Each participant has to rate 8 treatments at the end of experiments and the total sample size is 576 (72×8). The variable *Round* indicates the length of treatments in each session. As mentioned in 2.4, the round numbers were rotated in different session, so this must be controlled in the regression. The variable of *Treatment* is the dummy variables which identify the different treatments. In the estimation, this variable will generate a series of dummy variables of treatments which represent the identified treatments. The reference level of dummy variables can usually be the baseline.

The variable of Profit is somewhat complicated to construct. The original dataset of profits is the matrix with 72×71 observations. To make the dataset comparable with the dependent variable, the values of profit per round were calculated. We calculated by summing the profits in a given round number for each treatment and then divided the summation by the round number. We redistributed side payments by dividing the one-time side payment by the round number, multiplied by the corresponding factors to generate the nominal payments per round and added them to the corresponding profits in each round. Hence, we generated the series of data of profits with 72×8 observations.

The first estimation is the model of opinion on benefit to individual. The results of estimation are shown in table below.

Table 12 The estimations on beneficial to individual

Parameter	Estimation 1	Estimation 2	Estimation 3
Intercept	8.44*** (2.00)	8.01*** (2.01)	0.04 (4.85)
Round	-0.01 (0.05)	-0.01 (0.05)	-0.06 (0.06)
Profits	4.4E-05 (1.3E-04)	0.06 (0.13)	0.81* (0.41)
Baseline 2	-0.09 (0.31)		
SP_0_23500	-1.32*** (0.36)	-1.30*** (0.35)	11.08** (5.27)
SP_0_0	-3.63*** (0.45)	-3.55*** (0.45)	4.85 (5.32)
SP_50_7144	-1.53*** (0.33)	-1.50*** (0.32)	9.11 (5.82)
SP_0_30644	-0.62 (0.47)	-0.62 (0.46)	6.85 (5.29)
Tax_50	-2.30*** (0.30)	-2.25*** (0.29)	13.69** (6.17)
Tax_0	-3.34*** (0.45)	-3.26*** (0.45)	8.65 (5.58)
Baseline 1①	-	-	-
Profits * *SP_0_23500*			-1.04** (0.45)
Profits * *SP_0_0*			-0.72 (0.49)
Profits * *SP_50_7144*			-0.91* (0.49)
Profits * *SP_0_30644*			-0.66 (0.44)
Profits * Tax_50			-1.40** (0.54)
Profits * Tax_0			-1.12** (0.53)
Profits *Baseline 1			-
N	576	504	504
AIC	2189.8	1858.8	1851.9
BIC	2194	1862.9	1855.9
R^2	0.58	0.59	0.60

Note: ① the meanings of Baseline1 in the three estimations are different. The Estimation1 indicates that separation of two baselines. The *Baseline 1* in the Estimation2 and Estimation3 represent the combination of two baselines.

The table provides three estimations. The first estimation is the model which separates the two baselines and the Baseline1 is the reference; however, the results of show that there are no significant difference between the two baselines. Thus, the second estimation combined the two baselines together and set the baseline 1 as the reference. In this case, the total sample size was reduced from 576 to 504 (72×7). The values of AIC and BIC provide criteria to assess the relative quality of a statistical model. The Table 12 indicates that the Estimation2 is better than the Estimation1 because the index of AIC and BIC decreases greatly. Compared with Estimation2, the AIC and BIC decreases slightly in Estimation3 but three of the interaction terms in Estimation3 significantly affect the rate on beneficial to individual at the significant level of 0.05. Besides, R^2 also increases slightly from model 2 to model 3. In sum, the model 3 is the best model to explain the impact on opinion of beneficial to individual.

The table shows that without interactions with treatment, profits have positive impact on opinions of beneficial to individual and this impact is significant only at the level of 10%. This means participants rate the treatment higher when they are better off. The interactions of profits and treatments indicate the contribution of treatments on opinions. The results show that the rate of benefit to individual in *Tax_0* is lower than the rate in the Baseline by 1.12 and the impact is significant at the significance level of 5%. The rate is even significantly lower in *Tax_50* which is 1.4 when the threshold level increases from 0 to 50. The table shows that *SP_0_23500* significantly decrease the rates at the significance level of 5% and the value of coefficient is smaller than the coefficients of tax treatment without side payment. Another tax treatment with redistribution: *SP_50_7144* also has less negative impact on rates than the tax treatments without redistribution and its impact is significant at the significance level of 10%. This indicates that redistribution of tax revenue offset the negative impact from imposing tax policy. The comparison of average values of profits and rates verify that the positive effect is counterbalanced by a negative effect probably due to the rejection of tax policy.

Table 13 The estimations on beneficial to group

Parameter	Estimation 1	Estimation 2	Estimation 3
Intercept	5.41** (2.12)	3.55* (2.08)	0.57 (5.05)
Round	0.01 (0.05)	0.05 (0.05)	0.05 (0.06)
Profits	8.5E-05 (1.4E-04)	0.20 (0.13)	0.46 (0.43)
Baseline 2	-0.06 (0.33)		
SP_0_23500	-0.55 (0.38)	-0.69* (0.36)	4.13 (5.49)
SP_0_0	-1.74*** (0.48)	-1.41*** (0.47)	0.42 (5.54)
SP_50_7144	-0.60* (0.35)	-0.68** (0.33)	-1.46 (6.06)
SP_0_30644	-0.28 (0.50)	-0.57 (0.48)	1.93 (5.50)
Tax_50	-0.69** (0.32)	-0.64** (0.30)	5.43 (6.42)
Tax_0	-1.34*** (0.47)	-1.01** (0.47)	2.70 (5.81)
Baseline 1①	-	-	-
Profits * *SP_0_23500*			-0.40 (0.47)
Profits * *SP_0_30644*			-0.12 (0.51)
Profits * *SP_50_7144*			0.05 (0.51)
Profits * *SP_0_30644*			-0.23 (0.46)
Profits * Tax_50			-0.54 (0.56)
Profits * Tax_0			-0.34 (0.55)
Profits *Baseline 1			-
N	576	504	504

AIC	2249.9	1885.9	1885
BIC	2254.1	1890	1889.1
R^2	0.429	0.482	0.487

Note: ① the meanings of Baseline1 in the three estimations are different. The Estimation1 indicates that separation of two baselines. The *Baseline 1* in the Estimation2 and Estimation3 represent the combination of two baselines.

We not only explore how participants rate the different policy institutions based on their welfare improvement, but consider how the different policy institutions benefit the group who share the same aquifer. Among the three models in Table 13, we combined two baselines together in model 2 and model 3 because in insignificant difference between these two baselines in model 1.

The model 2 indicates that profits don't have significant impact on rates although the coefficient is positive. Without the consideration of interaction between profits and treatments, the tax treatments have negative impact on rates. More specifically, the tax treatments without redistribution (e.g. *Tax_0, Tax_50* and *SP_0_0*) have significantly negative impact on rates. The coefficient of *Tax_50* is -0.64 while the coefficients of *Tax_0* and *SP_0_0* are -1.01 and -1.41, respectively. This indicates that the tax treatment with high-level threshold (*Tax_50*) has less negative impact on rates than the tax treatment with low-level threshold does (*Tax_0* and *SP_0_0*). For the tax treatments with redistributions, only *SP_50_7144* and *SP_0_23500* have significant impact on rates at the significance levels of 5% and 10%, respectively. The coefficients of tax treatment with redistribution are smaller than the tax treatment with low-level threshold, but a bit higher than the tax treatment with high-level threshold. The model 3 includes the interaction between profits and treatments. The estimation indicates that model 3 has a higher AIC and BIC as well as the R^2 than the model 2. Model 3 also indicates that profits have positive but not significant impact on rate on beneficial to group. For the effects from tax policies, the model 3 shows that most of the tax policies have negative coefficients in the estimation except for *SP_50_7144*. Unfortunately, none of the independent variables are statistically significant.

Table 14 The estimations on fairness

Parameter	Estimation 1	Estimation 2	Estimation 3
Intercept	7.92*** (2.21)	7.81*** (2.22)	4.38 (5.38)
Round	0.02 (0.05)	0.03 (0.05)	-5.0E-04 (0.06)
Profits	1.0E-04 (1.43E-04)	-0.08 (0.14)	0.26 (0.46)
Baseline 2	0.17 (0.35)		
SP_0_23500	-0.77* (0.40)	-0.89** (0.39)	6.06 (5.85)
SP_0_0	-2.72*** (0.50)	-2.74*** (0.50)	-1.17 (5.90)
SP_50_7144	-0.51 (0.36)	-0.61* (0.35)	7.00 (6.46)
SP_0_30644	-0.22 (0.53)	-0.36 (0.51)	1.76 (5.86)
Tax_50	-0.54 (0.33)	-0.61* (0.33)	10.65 (6.85)
Tax_0	-1.90*** (0.49)	-1.92*** (0.50)	1.73 (6.19)
Baseline 1①	-	-	-
Profits * *SP_0_23500*			-0.57 (0.50)
Profits * *SP_0_0*			-0.07 (0.55)
Profits * *SP_50_7144*			-0.64 (0.55)
Profits * *SP_0_30644*			-0.21 (0.49)
Profits * Tax_50			-1.00* (0.60)
Profits * Tax_0			-0.31 (0.59)
Profits *Baseline 1	-	-	-
N	576	504	504
AIC	2290.9	1943.6	1938.4

BIC	2295.1	1947.7	1942.5
R^2	0.490	0.518	0.527

Note: ① The meanings of Baseline1 in the three estimations are different. The Estimation1 indicates that separation of two baselines. The *Baseline 1* in the Estimation2 and Estimation3 represent the combination of two baselines.

The last question focuses on fairness of the policy. We want to know how participants evaluate the state and condition of the policy being fair. The model selection in this part is similar to the case of beneficial to group. Model 2 andModel 3 are preferred because the insignificant difference between *Baseline1* and *Baseline2*.

The model 2 and model 3 indicate the opposite impacts of profits although both of them are not significant. Without the consideration of interaction between profits and treatments (Model 2), the tax treatments have negative impact on rates. More specifically, the tax treatments without redistribution (e.g. *Tax_0, Tax_50* and *SP_0_0*) have significantly negative impact on rates. The tax treatments with low-level threshold (*Tax_0* and *SP_0_0*) have significantly negative impact on rates at the significance level of 1% and the coefficients are -1.92 and -2.74, respectively. The tax treatment with high-level threshold is only significant at the level of 10% and its coefficient is -0.61. The tax treatments with redistribution have smaller coefficients than the treatments without redistribution. However, only the treatments of *SP_0_23500* and *SP_50_7144* are significant at the significance levels of 5% and 10%, respectively. The coefficients of these two treatments are less than the tax treatment with low-level threshold and larger than the tax treatment with high-level threshold.

The model 3 includes the interaction between profits and treatments. The estimation indicates that model 3 has a higher AIC and BIC as well as the R2 than the model 2. In the model 3, all of the tax treatments have negative coefficients than baseline but only the impact of treatment of Tax_50 is significant at the significance level of 10%.

Chapter 4

DISCUSSION AND CONCLUSION

This article used experimental economics techniques with a spatially explicit model on the optimal groundwater management and evaluated the efficiency of tax policies by comparing the pumping behaviors and welfare changes in social optimal scenario and baseline. The numeric optimization was carried out based on several simplifying assumptions on groundwater management formulation and was solved by linking software of Modflow, MATLAB and z-Tree.

Our results show that the implementation of tax policies changes the groundwater users' extraction systematically and reduces the pumping rate significantly from the baseline. In spite of the potential in groundwater use conservation, this paper also addresses the excessive effect of tax policies on groundwater management. This finding reminds policy-makers being careful of using the tool of tax in groundwater management. In addition, all of the pumping decisions in each round of tax policies are clustered, supporting the theoretical design that all tax treatments provide the same marginal incentive and participants recognize these incentives.

Side payments in this paper are provided in different experimental design to lessen the distributional burdens of tax to groundwater users. The results support the judgment that groundwater users' welfare crucially depend on the redistribution of tax revenues. If the tax revenues do not rebate properly, the welfare of groundwater users would reduce greatly to the levels which are even worse than the unregulated scenario (baseline). The side-payment treatments are able to generate the same welfare levels for the users as the baseline does, but was also able to drive the users to the intertemporally socially optimal pumping rates. This paper also advocates that the redistribution of tax revenue in groundwater management could be rebate before the implementation of tax policies.

The most innovative contribution to literatures is the collection of participants' opinions on different policy instruments. Surprisingly, participants' rates on the different tax policies did not always match their received welfare. Participants tended to rate the tax treatments without redistribution of tax revenue very low. This can be explained because they gained less profit than the unregulated scenario. However, participants also rate the tax treatment with side payments lower than the baseline in all of the three aspects although they were better off during these treatments. The further estimations show that tax policies have negative impacts on rates.

In sum, this research believes that the tax policies with redistribution of tax revenue are recommended to correct the overuse of groundwater because they reduce the pumping rate and maintain the users' welfare level as the unregulated cases. But it is notable that the effect of tax policies on groundwater management tends to be excessive. This result may partly contribute the finding that participants reject tax policies which make them better off. Confiscation payments could enhance groundwater users' welfare level and the acceptance rate of tax policies to some extent, but could not fundamentally change the users' opposition to tax policies. Therefore, when implementing tax policies on groundwater management, policymakers should design a feasible distribution of tax revenue and elaborate the policies proposals to lessen the rejection from groundwater managers and users.

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APPENDIX

A INTRODUCTION

This experiment studies individual decision-making. If you follow these instructions and make careful decisions you will earn money that will be paid to you privately **in cash** at the end of the session. The money you earn depends on your decisions and the decisions of others. Your profits will be measured in tokens, which will be added up over the course of the experiment. At the end of the experiment, you will be paid in cash at the rate of **26,000 tokens = $1**. Please do not communicate with other participants in the experiment. If you have a question, raise your hand and an experiment administrator will assist you.

The experiment will begin with five **Practice Rounds** to allow you to become familiar with the software. You will then play a number of separate **Sections** for actual cash. Each Section has a number of decision Rounds. The number of decision Rounds in each Section will be determined randomly by the computer. Specifically, there is a 10% chance that each Round will be the final Round of that Section. In other words, at the conclusion of each Round, there is a 90% chance that you will play at least one additional Round of that Section.

In the experiment, you will play the role of a **Firm manager**. Your Firm generates earnings by pumping water from a **groundwater resource** (referred to as an "**aquifer")**. Your Firm is one of a group of four Firms. Each Firm in your group **pumps** water from the same aquifer. Your Firm number will be indicated on your computer screen when the experiment begins. You will not know the identities of the other Firms in your group. Figure 1 shows a map of the Firm locations and provides a visual representation of the aquifer.

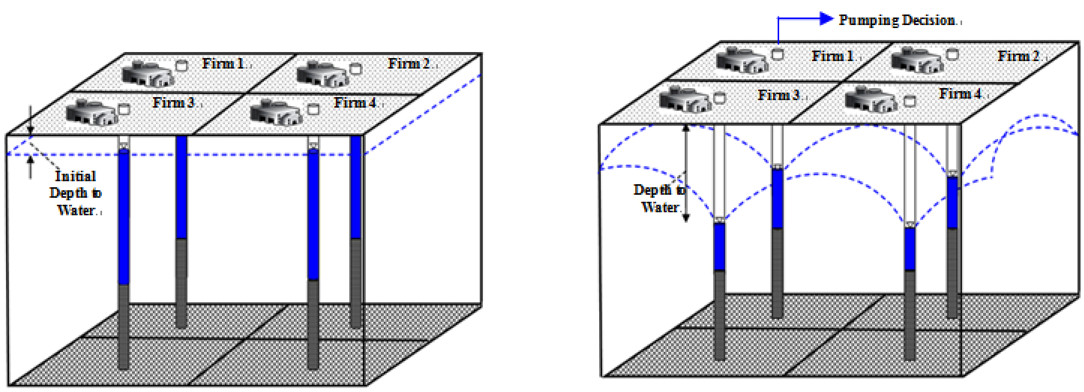


Figure 10 Four Firms pump water from a common aquifer

In each Round, you must decide how many units of water to pump from the aquifer. Pumping water allows your Firm to generate revenue, but pumping is also costly. The greater the depth to the groundwater, the more costly it is to pump the water to the surface. Importantly, the more water that you and other Firms in your group pump in a given Round, the greater the depth to water in future Rounds. This means that pumping more water in the current Round can lead to lower profits in future Rounds.

Figure 2 shows how the depth to water changes with different pumping decisions. The figure shows that higher pumping decisions lead to greater depth to water as the number of Rounds increase.

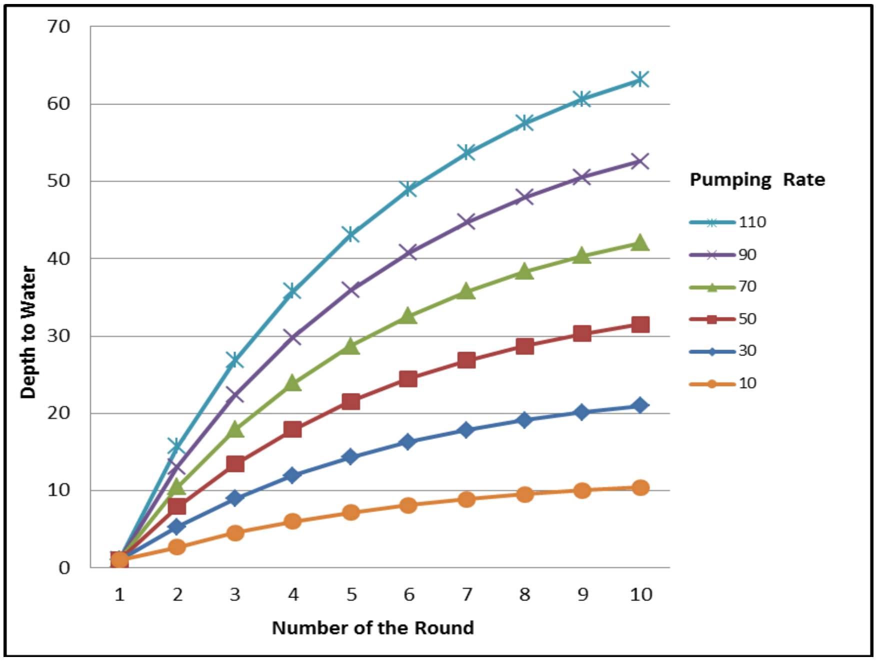
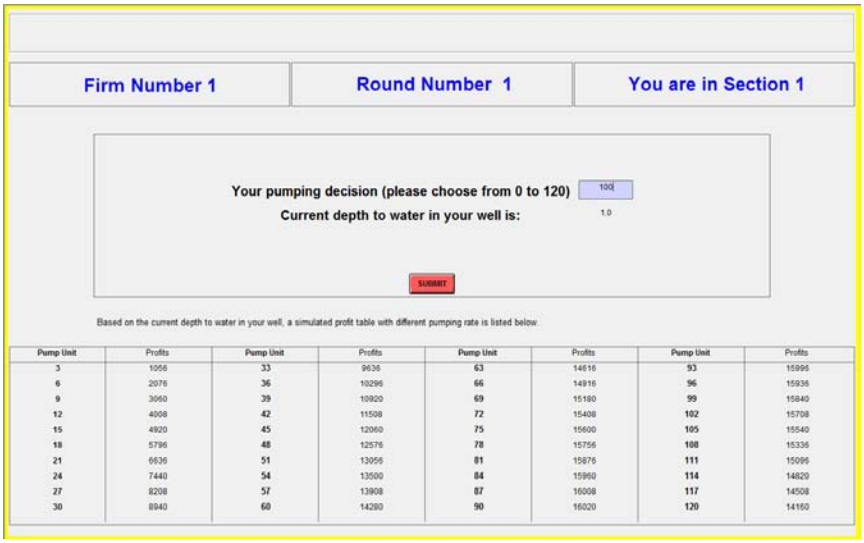


Figure 11 Depth to water with different pumping decisions (if four Firms pump at same rate)

Note: The number of Rounds in this figure is an example. In the experiment, the number of Rounds in each of the Sections will be determined randomly.

1. Pumping Decision

In each Round, all Firms make an anonymous pumping decision. Figure 3 shows an example of the decision screen. You type your pumping decision in the box labeled **Pumping Decision,** then click on the red button labeled <SUBMIT> to finalize your decision. At the bottom of the screen, there is a profit table based on the current depth to help you make your decision.



Pump Unit	Profits	Pump Unit	Profits	Pump Unit	Profits	Pump Unit	Profits
3	1056	33	9636	63	14616	93	15996
6	2076	36	10296	66	14916	96	15936
9	3060	39	10920	69	15180	99	15840
12	4008	42	11508	72	15408	102	15708
15	4920	45	12060	75	15600	105	15540
18	5796	48	12576	78	15756	108	15336
21	6636	51	13056	81	15876	111	15096
24	7440	54	13500	84	15960	114	14820
27	8208	57	13908	87	16008	117	14508
30	8940	60	14280	90	16020	120	14160

Figure 12 Pumping Decision Screen

2. Determining profits

Your **Profits** in a particular Round are determined based on your revenue and cost in that round, both of which depend on the quantity of water that you pump and the depth to the water: Profits = Revenue – Cost. The Revenue that your Firm earns depends on the quantity of water that you pump in the following way:

$$\text{Revenue} = 360 \times \text{Units You Pump} - 2 \times (\text{Units You Pump})^2$$

For example, if you decide to pump 100 units, then your Revenue will be $360 \times 100 - 2 \times 100^2 =$ 16,000 tokens. Your Cost of pumping water in a given Round depends on the number of units you pump and the depth to water. The greater the depth to the groundwater, the higher the Cost:

$$\text{Cost} = 2 \times \text{Units You Pump} \times \text{Depth}$$

If the depth to water in your well is 1 (as in the first Round) and you pump 100 units, the Costs will be $2 \times 100 \times 1 = 200$ tokens. Thus, your total Profit will be 16,000 – 200 =15,800 tokens.

Your depth to the groundwater is determined by the quantity of water that you pumped **and** by the pumping decisions of the other Firms in your group in previous Rounds. The impact of other Firms' pumping decisions on your well's depth to water decrease with your distance from their wells. For instance, in Figure 1, if you are Firm 1 then the pumping decisions of Firm 2 and Firm 3 will have a larger impact on the your depth in future Rounds than Firm 4, which is the farthest away from your well. The Firm that has the largest impact on your future depth to water is your Firm.

3. Results

Once all players have submitted their pumping decisions in a particular Round, you will see the Profit Screen that provides you with information on the depth to water in the next Round and a summary of the results for your Firm for that Round and from all previous Rounds. An example of the results screen is provided below. The screen indicates your well depth, Round profits and cumulative earnings. A history table is displayed at the bottom of the screen, which records your pumping choices and profits in the previous Round.

Figure 4: Sample Profit Screen with Hypothetical Results

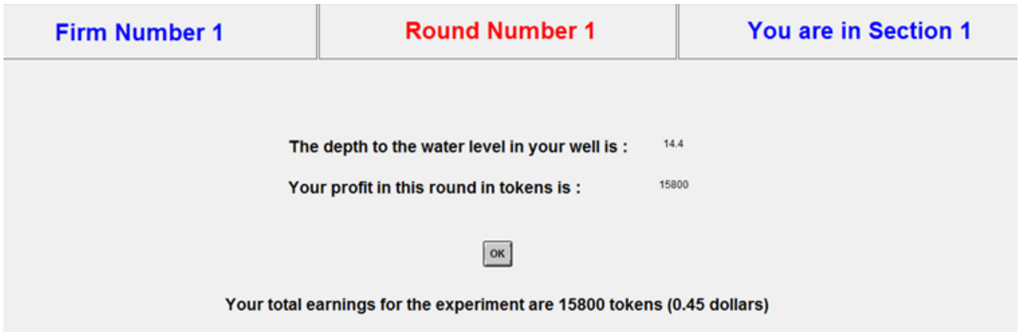


Figure 13 Sample Profit Screen with Hypothetical Results

Pumping Game

In the Pumping Game, you will see the Decision Screen, which is provided below. Once all players have submitted their pumping decisions in a particular Round, you will see the Profit Screen. This screen provides the depth to the groundwater in your well and the summary of profits, including the profit in the current Round and the total profits for all Rounds.

Sample Decision Screen with Hypothetical Results

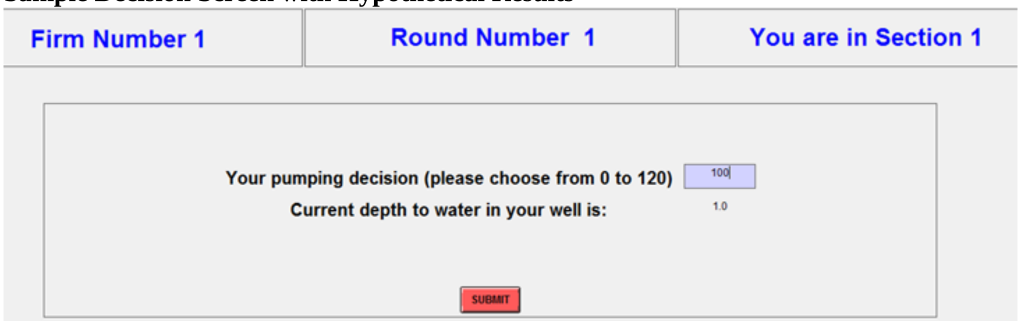


Figure 14 Sample Decision Screen with Hypothetical Results

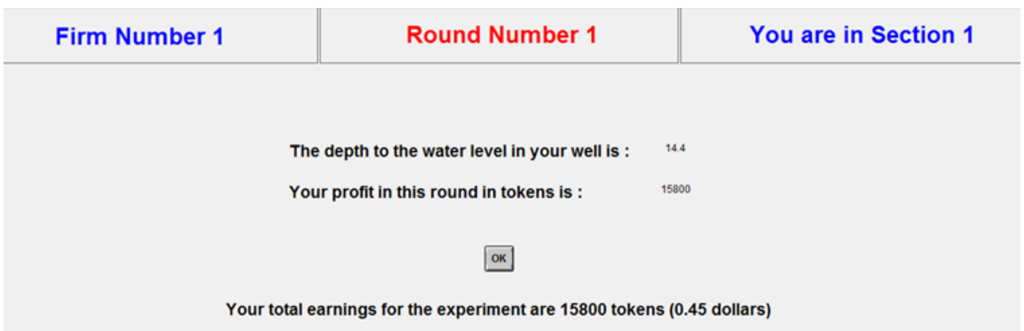


Figure 15 Sample Profit Screen with Hypothetical Results

Pumping Game with Tax of 47 tokens per unit of water pumped

In this Section, you must pay a tax on the amount of water that you pump. The tax is **47** tokens per unit pumped. The more water you pump, the more total tax you pay. But remember that each unit is taxed at the same rate. The tax payment is described by the following equation:

$$\text{Tax} = 47 \times \text{Units You Pump}$$

For example, if you pump 100 units, the tax will be $47 \times 100 = 4{,}700$ tokens. **The tax payment will not be given back to you.** The resulting Profit function is shown below where the Revenue and Cost are calculated as described previously:

$$\text{Profits} = \text{Revenue} - \text{Cost} - \text{Tax}$$

You will also see the same screens as before, and the profit table will have additional information on **before-tax** and **after-tax** profits. The **Start Screen** shows you the specific details for the section. The **Decision Screen** shows the unit tax when you make choices. The **Profit Screen provides** and the current depth after you make that choice and a summary of profits including the profits before tax and profits after tax are provided. The profits (after tax) are equal to the profits (before tax) minus the tax payment.

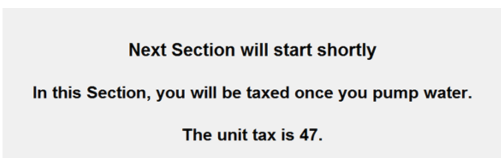


Figure 16 Sample Start Screen

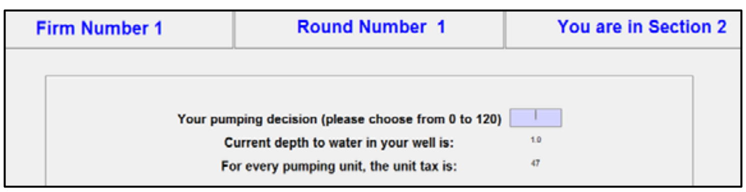


Figure 17 Sample Decision Screen

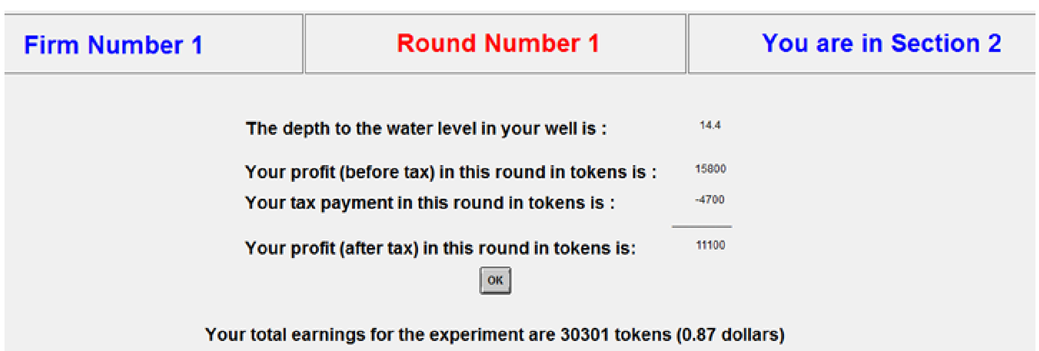


Figure 18 Sample Profit Screen

Pumping Game with Tax of 47 tokens per unit of water pumped on pumping above 50 units

In this Section, you may have to pay a tax on the amount of groundwater that you pump. If you pump above 50 units, the tax is **47** tokens per unit pumped. You only pay this tax on units pumped above 50 in any one round. The more water you pump above 50 units, the more tax you pay. But remember that each unit above 50 is taxed at the same rate. The tax payment is described by the following equation:

If pumping is 50 or below, the Tax = 0.

If pumping is 51 or more, the Tax = 47 $\times$ (Units You Pump – 50).

For example, if you pump 100 units, the tax will be 47$\times$ (100 – 50) = 2,350 tokens. This tax payment will not be given back to you. The resulting Profit function is shown below where the Revenue and Cost are calculated as described previously:

Profits = Revenue – Cost – Tax

You will also see the same screens as before, and the profit table will have additional information on **before-tax** and **after-tax** profits. The **Start Screen** shows you the specific details for the section. The **Decision Screen** shows the unit tax when you make choices. The **Profit Screen provides** and the current depth after you make that choice and a summary of profits including the profits before tax and profits after tax are provided. The profits (after tax) are equal to the profits (before tax) minus the tax payment.

Next Section will start shortly

In this Section, you will be taxed if you pump more than 50 units of water in each period.

The unit tax is 47.

Figure 19 Sample Start Screen

Based on the current depth to water in your well, a simulated profit table (**after tax**)with different pumping rate is listed below.

Pump Unit	Profits(after tax)	Tax Payment	Pump Unit	Profits(after tax)	Tax Payment	Pump Unit	Profits(after tax)	Tax Payment	Pump Unit	Profits(after tax)	Tax Payment
3	1056	0	33	9636	0	63	14005	611	93	13975	2021
6	2076	0	36	10296	0	66	14164	752	96	13774	2162
9	3060	0	39	10920	0	69	14287	893	99	13537	2303
12	4008	0	42	11508	0	72	14374	1034	102	13264	2444
15	4920	0	45	12060	0	75	14425	1175	105	12955	2585
18	5796	0	48	12576	0	78	14440	1316	108	12610	2726
21	6636	0	51	13009	47	81	14419	1457	111	12229	2867
24	7440	0	54	13312	188	84	14362	1598	114	11812	3008
27	8208	0	57	13579	329	87	14269	1739	117	11359	3149
30	8940	0	60	13810	470	90	14140	1880	120	10870	3290

Figure 20 Sample Simulated Profit Table in Decision Screen

Pumping Game with Tax of 47 tokens per unit of water pumped with a Payment of 30,644

In this Section, you must pay a tax on the amount of water that you pump, but you will receive an up-front payment of 30,644. The more water you pump, the more total tax you pay. But remember that each unit is taxed at the same rate. The tax payment is described by the following equation:

$$\text{Tax} = 47 \times \text{Units You Pump}$$

For example, if you pump 100 units, the tax will be $47 \times 100 = 4{,}700$ tokens. **The tax payment will not be given back to you.** The resulting profit functions are shown below where the Revenue and Cost are calculated as described previously:

If Round number is 1, Profits = Revenue – Cost – Tax + Payment

If Round number is 2 or more, Profits = Revenue – Cost – Tax

You will see the same screens as before, and the profit table will have additional information on before-tax and after-tax profits. **In this Section, you are given an up-front payment of 30,644 tokens at the start of the Section. This payment will go to your total profits account**. The payment is provided **only in the first round**. You will see the screen below in this section. In the **Decision Screen**, you see the unit tax and the payment amount when you make choices.

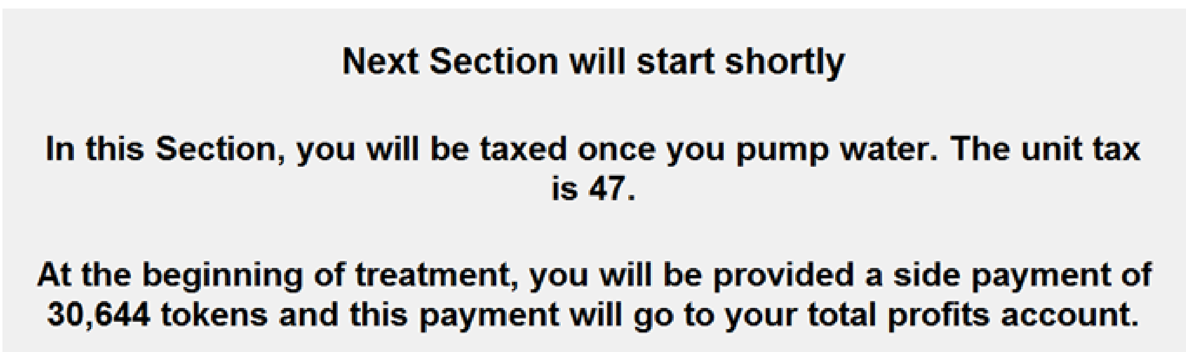


Figure 21 Sample Start Screen

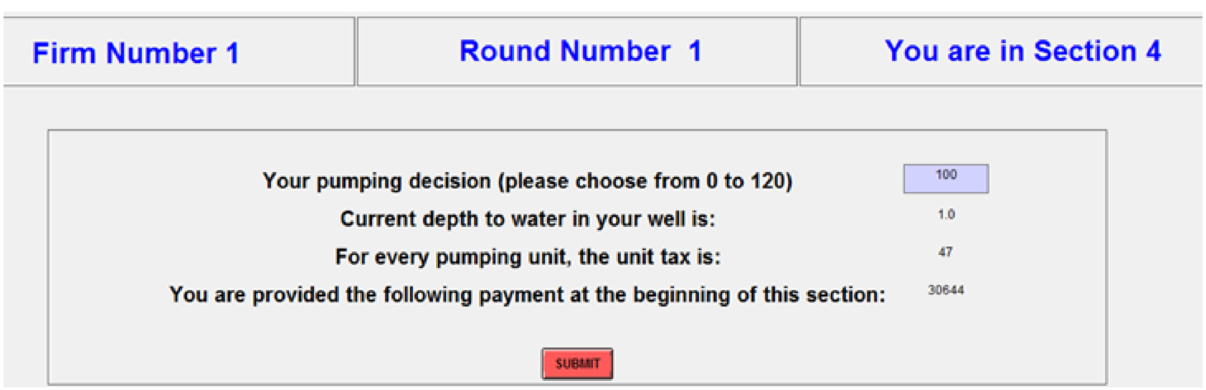


Figure 22 Sample Decision Screen

Pumping Game with Tax of 47 tokens per unit of water pumped on pumping above 50 units and a Payment of 7,144 tokens

In this Section, you may have to pay a tax on the amount of groundwater that you pump, but you will receive an up-front payment of 7,144. If you pump above 50 units, the tax is **47** per unit pumped. You only pay this tax on units pumped above 50 in any one round. The more water you pump above 50 units, the more total tax you pay. But remember that each unit above 50 is taxed at the same rate. The tax payment is described by the following equation:

If pumping is 50 or below, the Tax = 0.

If pumping is 51 or more, the Tax = 47 $\times$ (Units You Pump – 50).

For example, if you pump 100 units, the tax will be 47$\times$ (100 – 50) = 2,350. **The tax payment will not be given back to you.** The resulting profit functions are shown below where the Revenue and Cost are calculated as described previously:

If Round number is 1, Profits = Revenue – Cost – Tax + Payment.

If Round number is 2 or more, Profits = Revenue – Cost – Tax

You will see the same screens as before, and the profit table will have additional information on before-tax and after-tax profits. **In this Section, you are given an up-front payment of 7,144 tokens at the start of the Section. This payment will go to your total profits account**. The payment is provided **only in the first round**. You will see the screens below in this section. In the **Decision Screen**, you see the unit tax and the number of payment when you make choices.

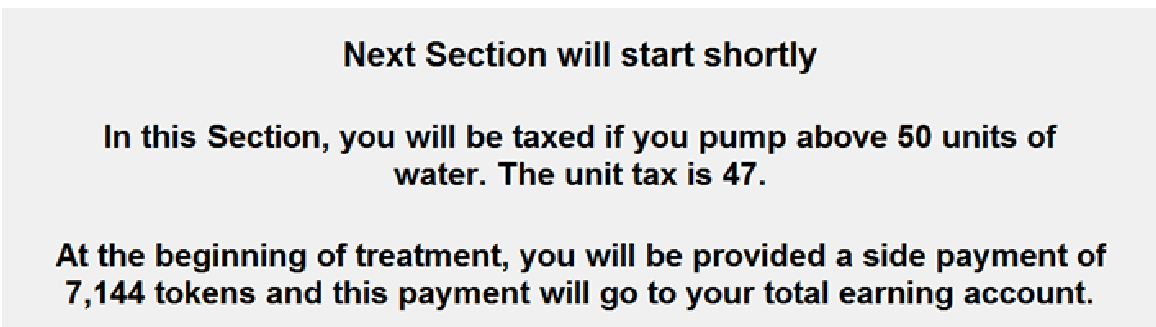


Figure 23 Sample Start Screen

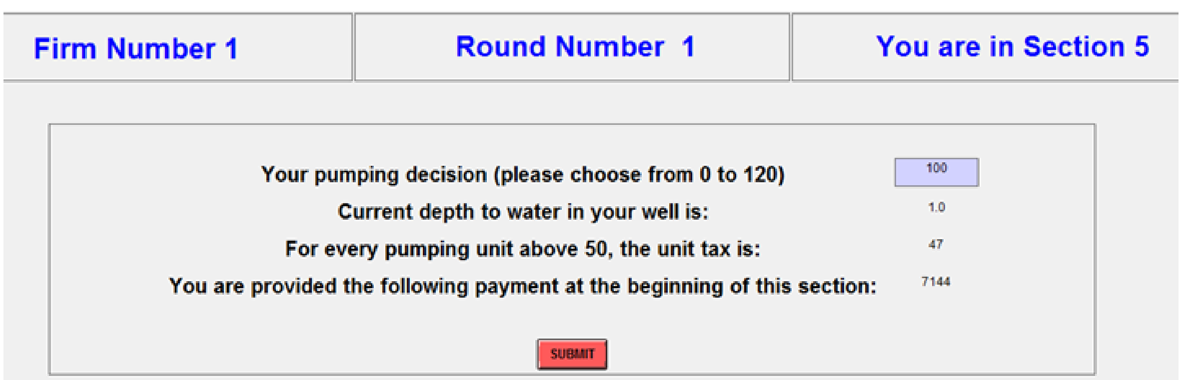


Figure 24 Sample Decision Screen

Pumping Game with Tax of 47 tokens per unit of water pumped on pumping above 0 units and a Payment of 0

In this Section, you may have to pay a tax on the amount of groundwater that you pump. If you pump above 0 units, the tax is **47** tokens per unit pumped. You only pay this tax on units pumped above 0 in any one round. The more water you pump above 0 units, the more total tax you pay. But remember that each unit above 0 is taxed at the same rate. The tax payment is described by the following equation:

If pumping is 0, the Tax = 0.

If pumping is 1 or more, the Tax = 47 $\times$ (Units You Pump – 0)

For example, if you pump 100 units, the tax will be 47$\times$100 = 4,700 tokens. **The tax payment will not be given back to you.** The resulting profit function is shown below where the Revenue and Cost are calculated as described previously:

Profits = Revenue – Cost – Tax

You will see the same screens as before, and the profit table will have additional information on before-tax and after-tax profits. **In this Section, you are given an up-front payment of 0 tokens at the start of the Section.**

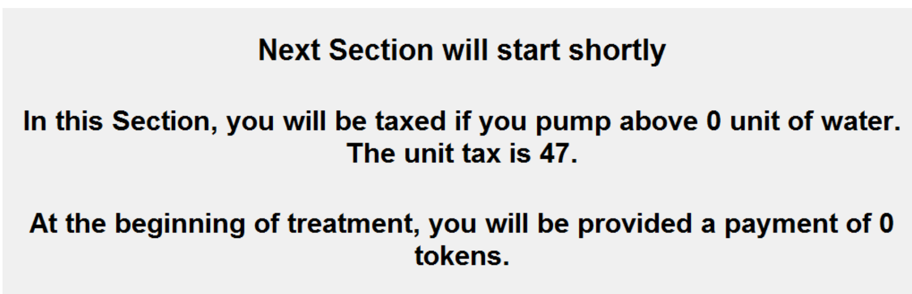


Figure 25 Sample Start Screen

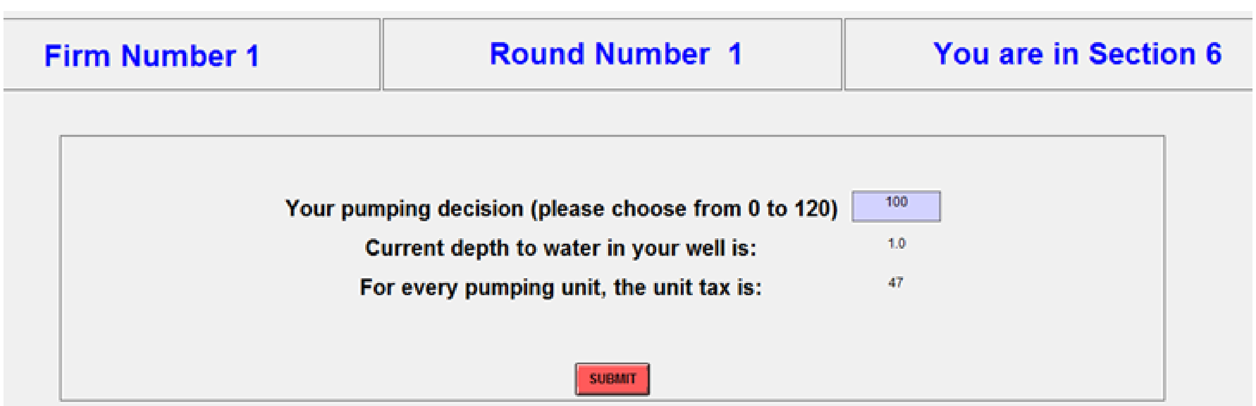


Figure 26 Sample Decision Screen

Pumping Game with Tax of 47 tokens per unit of water pumped on pumping above 0 units and a Payment of 23,500

In this Section, you may have to pay a tax on the amount of groundwater that you pump, but you will receive an up-front payment of 23,500. If you pump above 50 units, the tax is **47** per unit pumped. You only pay this tax on units pumped above 50 in any one round. The more water you pump above 50 units, the more total tax you pay. But remember that each unit above 50 is taxed at the same rate. The tax payment is described by the following equation:

If pumping is 0, the Tax = 0.

If pumping is 1 or more, the Tax = 47 $\times$ (Units You Pump – 0)

For example, if you pump 100 units, the tax will be 47$\times$100 = 4,700. **The tax payment will not be given back to you.** The resulting profit functions are shown below where the Revenue and Cost are calculated as described previously:

If Round number is 1, Profits = Revenue – Cost – Tax + Payment.

If Round number is 2 or more, Profits = Revenue – Cost – Tax

You will see the same screens as before, and the profit table will have additional information on before-tax and after-tax profits. **In this Section, you are given an up-front payment of 23,500 in tokens at the start of the Section. This payment will go to your total profits account**. The payment is provided **only once** In the **Decision Screen**, you see the unit tax and the number of payment when you make choices.

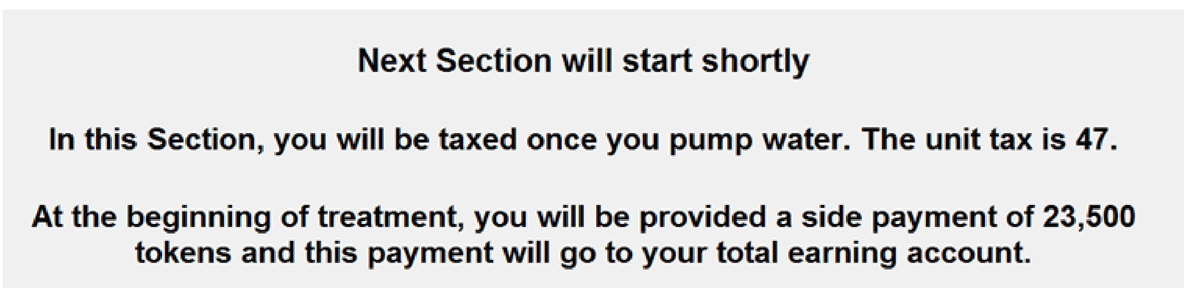


Figure 27 Sample Start Screen

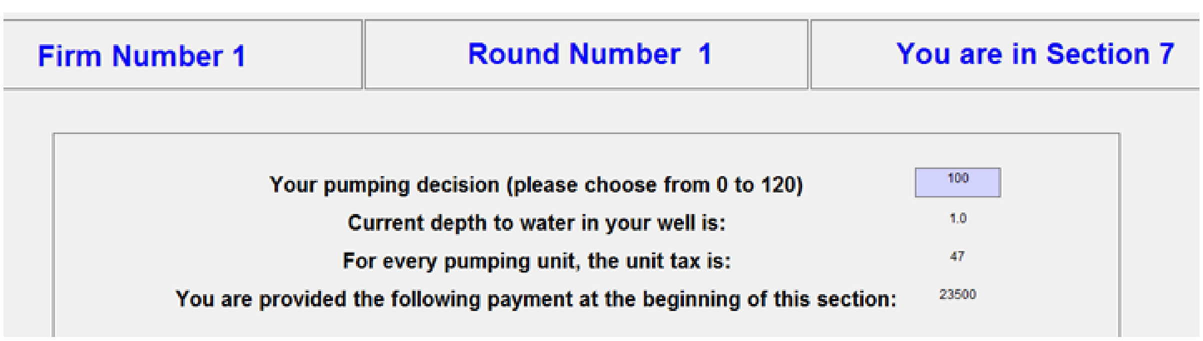


Figure 28 Sample Decision Screen

Pumping Game

In the Pumping Game, you will see the Decision Screen, which is provided below. Once all players have submitted their pumping decisions in a particular Round, you will see the Profit Screen. This screen provides the depth to the groundwater in your well and the summary of profits, including the profit in the current Round and the total profits for all Rounds.

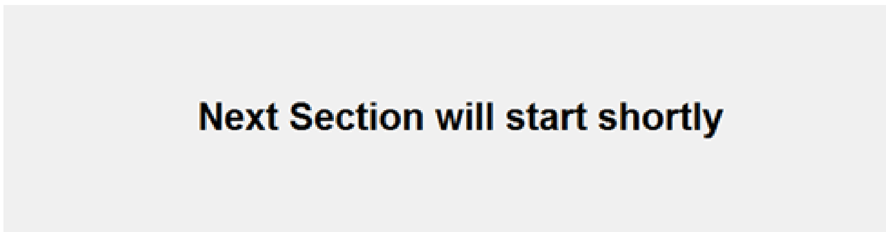


Figure 29 Sample of Start Screen

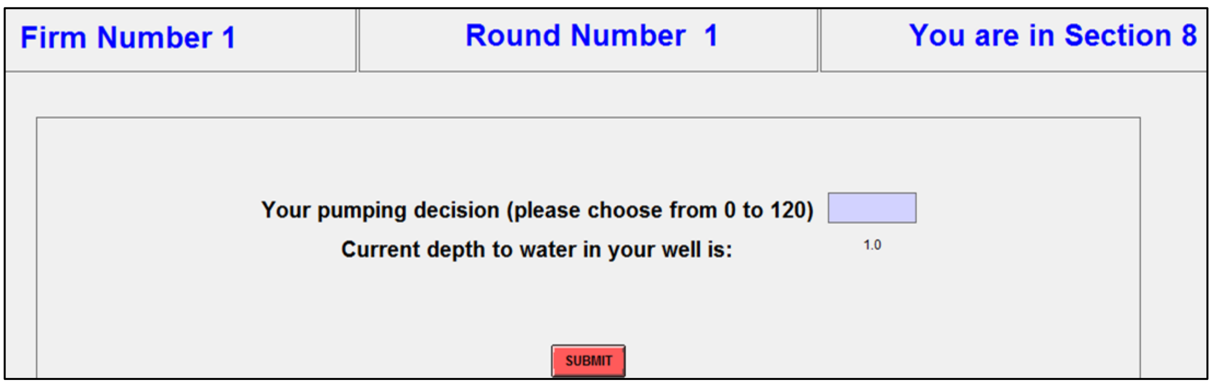


Figure 30 Sample of Decision Screen

Opinion Survey

After Sections, you will participate in a quick survey about your opinions about the 8 sections you just played. Figure 6 provides a view of the screen indicating that the Section has ended. Clicking the “OK” button will then bring you to a screen where you will participate in a survey.

The computer has determined that this section has ended.
Please click OK for a survey.

Figure 31 Sample Screen to Participate in the Survey

In the **Survey Screen**, you will evaluate the current Section and indicate your opinion from 1 to 10, where 1 indicates that you had the lowest possible opinion of the section you just played, while 10 indicate the highest possible opinion. A value of 5 indicates that you do not have a favorable or unfavorable opinion. Feel free to use any whole number between 1 and 10 to convey your opinion. There are two questions: the first one asks you to make your evaluation based on your own Firm and the second one asks your evaluation from the perspective of the entire 4-firm group. Once you finish the survey, click “OK” to continue the experiment.

(You just played 8 sections of the common aquifer game. Sections 1 and 8 had the same rules, but Sections 2-7 each had different rules. We want to know your opinions about these different rules. Note: please rate from 1 to 10, where 1 is the least favorable opinion possible and 10 is the most favorable opinion possible. A rating of 5 would indicated that you have neither a favorable or unfavorable opinion about the section.)

Section 1 and 8 (No tax, no up-front payment)

Q: On a scale of 1 to 10, what is your opinion of this Section's rules as it affects you?"

Q: On a scale of 1 to 10, what is your opinion of this Section's rules as it affects your group with 4 firms?"

Figure 32 Sample Survey Screen with Hypothetical Results

B HUMAN SUBJECTS PROTOCOL AMENDMENT

University of Delaware

Protocol title: An Experimental Economics Investigation of Groundwater Resource Dynamics

Principal Investigator:	Name:	Zhongyuan Liu (Graduate Student)
	Department/Center:	Applied Economics and Statistics
	Contact Phone Number:	302.740.2456
	Email Address:	liuzy@udel.edu
Advisor (if student):	Name	Joshua M. Duke, Grant Co-PI
	Department/Center:	Applied Economics and Statistics
	Contact Phone Number:	302-831-1309
	Email Address:	duke@udel.edu

Other investigators: Grant PI: Kent Messer, Applied Economics and Statistics
Grant Co-PI: Holly Michael, College of Earth, Oceans, and Environment

Investigator Assurance:
By submitting this protocol, I acknowledge that this project will be conducted in strict accordance with the procedures described. I will not make any modifications to this protocol without prior approval by the IRB. Should any unanticipated problems involving risk to subjects, including breaches of guaranteed confidentiality occur during this project, I will report such events to the Chair, Institutional Review Board immediately.

PROPOSED AMENDMENT Please provide a brief description in LAY language (understandable to an 8th grade student) of the purpose of the proposed amendment and the rationale behind the change(s).

This is a proposed amendment to previous approved IRB research. Previous economic experiments conducted under this grant with IRB approval used an approved protocol to investigate how decision makers interact with a computer-modeled aquifer. The same research approach is used in these experiments and the computer interface is almost the same as the last experiment (run by Jingyuan Li), but the decision space has changed. In this experiment, we propose to study the implications of tax instruments on ground water resource use. The proposed changes will not change the original approved experimental economics approach..

Background

Over the last several decades, groundwater resources have come to be increasingly relied upon to provide vital resources of clean drinking water and irrigation for food production across the world. Groundwater is the primary source of drinking water for over half of the world's population and accounts for at least one quarter of all water withdrawals. The stress on groundwater resources is likely to increase as climate change reduces the quantity and increases the variability of surface water flows. Groundwater extraction impacts the dynamics of complex hydrogeologic systems in ways which can denigrate the quality and quantity of water available for human and environmental use in the future. The combination of quality and quantity concerns implies that groundwater resources often have case-specific characteristics that generate unique behavioral incentives.

Details of proposed amendment

Tax policy instruments are a commonly considered tool to reduce the misallocation and overconsumption associated with a groundwater common pool resources (CPRs). The tax policy instrument is designed to force the user to consider the future value of the resource and incorporate external costs when making their withdrawal decision. The tax is often believed to have significant water-saving potential.

In our research, we will test two tax institutions. The first is a threshold, which we will vary with zero threshold equivalents to a fixed tax. Regression will test whether any threshold level delivers greater efficiency. The second institution is an existing well owner one-time payment. This one-time payment might be warranted because we are moving from a presumptive rights regime to a tax regime. Students are invited to represent a firm manager who makes anonymous individual pumping decisions using computers. Based on these data, we will investigate how people behave under various policy instruments and change their behavior when policies change, whether any threshold level or one-time payment level delivers greater efficiency; efficacy of policy instruments in comparison to an optimal groundwater use strategy.

1. **New Project Staff**

Please list any additional personnel, including students, who will be working with human subjects on this protocol who are not on original protocol (insert additional rows as needed):

NAME	**ROLE**	**HS TRAINING COMPLETE?**
Kent Messer	PI	Yes
Josh Duke	Co-PI	Yes
Holly Michael	Co-PI	Yes
Zhongyuan Liu	graduate student leader	Yes
Aidan Gause	undergraduate lab assistant	No
Benjamin Attia	undergraduate lab assistant	No
Deming, John Aaron	undergraduate lab assistant	No
Robinson, Gregory Andrew	undergraduate lab assistant	No

2. **PROCEDURES**

Describe **all changes** to procedures involving human subjects for this amendment.

This experiment is scheduled to begin as soon as possible in May 8-18 2014. Procedures involving the interaction with human subjects in this amendment remain unchanged from the original approved protocol.

3. **STUDY POPULATION AND RECRUITMENT**
Describe **any additional** subjects who will be invited to participate. Include age, gender and other pertinent information.

As in the original protocol, the study population will be undergraduate students that will be recruited using email. No personal information will be collected or used as a basis for participation in this research. An example recruitment email is as follows:

> "The Experimental Economics Laboratory for Policy and Behavioral Research is currently recruiting participants in a study of the economics of decision making. By participating in the study, you will have the opportunity to earn cash ranging from $15-$35, with an average payment of $25 determined by the decision made in the session.
>
> Space is limited and registration is made on a first come basis. To view the available experimental session and to register go to: http://agdev.anr.udel.edu/recruit/."

Describe what exclusionary criteria, if any will be applied.

As in the original protocol: only undergraduate students will be recruited. The initial recruitment will focus on students in a single college—Business and Economics. If recruitment lags, we intend to focus on students in other colleges.

Describe what (if any) conditions will result in PI termination of subject participation.
As in original protocol: Disruption of experiment session or endangerment to experiment participants to experiment administrators.

4. **RISKS AND BENEFITS**
Describe **any new risks** to participants resulting from the procedures requested in this amendment (risks listed here should be included in the consent document).
If risk is more than minimal, please justify.

The risks are not higher than an average computer task.

What steps will be taken to minimize risks?

No additional step will be taken.

Describe any direct benefits to participants.

There are no direct benefits. Indirect benefits come from better policy on the management of water resources.

Describe any future benefits to this class of participants.

None.

5. **COMPENSATION**
Will participants **receive additional compensation** for participation due to this amendment?

Yes.

If so, please include details.

Subjects will receive an initial payment for showing up to the experiment session and then additional payments will be made based on the subject's decisions during the experiment. The expected earnings will range from $15-$35 for this 1.5 hour experiment.

6. **DATA**
Are there **any changes to data** management as a result of this amendment?

No

7. **CONFIDENTIALITY**
Will participants be audiotaped, photographed or videotaped as part of the procedures requested by this amendment?

No

How will subject identity be protected?

Subjects will never be identified by anything other than a number.

Is there a Certificate of Confidentiality in place for this project? (If so, please provide a copy).

No

8. **CONSENT and ASSENT**

__X__ Consent form revisions are required and are attached for review.

Consent forms will be used. A sample is provided.

____ Additionally, child assent forms will be changed and are attached.

____No consent form revisions are required.

____ Consent forms will not be used (Justify request for waiver).

9. REVISED STUDY MATERIALS

Please list all supporting materials uploaded to IRBNet in support of this application. **Include one tracked-changed/highlighted copy and one clean copy of each revised document.**

C CONSENT FORM FOR AN EXPERIMENT IN THE ECONOMICS OF DECISION MAKING

Dr. Joshua Duke, Dr. Kent Messer and graduate student Zhongyuan Liu from Applied Economics and Statistics Department, Dr. Holly Michael from Geological Sciences Department at the University of Delaware are conducting an economic experiment on Groundwater Resources. Please read this consent form carefully and sign the final page.

PURPOSE/DESCRIPTION OF THE RESEARCH

- You are invited to participate in a research study about how individuals make decisions.
- You were selected as a possible participant from your stated interest in the experiment.
- Participants will be asked to use a simple computer program to make economic decisions.
- There will be up to 150 total participants in this study.

CONDITIONS OF SUBJECT PARTICIPATION

- Your decisions during the experiment will be kept confidential. However, please note that since our recruitment efforts involved both e-mail and the internet transmission, we cannot guarantee that this correspondence was private and secure. With the use of the internet, there is a potential chance that your responses to the recruitment efforts may be read by a third party.
- All participants are asked to keep their responses to all parts of the experiment confidential. Any intentional disruption of the experiment may result in the participant being asked to leave.

RISKS AND BENEFITS

- The risk for participating in this experiment is minimal. You have no greater risk from the experiment than you would from doing a similar amount of routine paperwork or computer-based activity in any similar classroom or computer laboratory.
- There are no substantial benefits to you from the research. By learning more about people's decision-making, we hope that the research will benefit society by helping economic institutions and government agencies understand people's behavior.

FINANCIAL CONSIDERATIONS

- You will earn cash averaging in the range of $15-$35 by participating in this experiment.
- The experiment will take approximately 2 hours-2: 15 to complete.
- Any costs incurred in order to attend the experiment are your own.

CONTACTS

- For questions related to research:
  Primary Investigator: Zhongyuan Liu (302) 740-2456, liuzy@udel.edu,
  Co-Investigator: Professor Joshua M. Duke (302) 831-1309, duke@udel.edu
- For questions relating to participant rights:
  Chair of Human Subjects Review Board: (302) 831-2137, hsrb-research@udel.edu.

SUBJECT'S ASSURANCES

- Your participation is strictly voluntary. You may refuse to participate before the study begins or withdraw at any time. If you withdraw from the experiment, you will be paid a show-up fee of $5.00. Your decision to withdraw will not affect you in any other way.

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I understand the information above and agree to participate in this study and my signature below indicates that I am 18 years of age or older.

Your Name (Please print): ________________________________

Your Signature: ________________________ **Date:** ________________