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The Carrot or the Stick: Water Allocation Strategies for Uzbekistan

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The Carrot or the Stick:
Water Allocation Strategies for Uzbekistan[1]

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Abstract

Irrigation water is a constrained common-pool resource in Uzbekistan that leads to an increasing competition over its allocation among farmers. We examine how the management of the commons in this region affects individual strategic behavior. We conduct an experiment with farmers from Uzbekistan in which two policies are analyzed, a penalty and a bonus. The paper studies a non-cooperative game and identifies the efficient use of water for irrigation. We compare our theoretical results with the experimental observations. Our findings suggest that the penalty and bonus mechanisms are effective in reducing individual water appropriation compared to the benchmark case in which these mechanisms are absent. Finally, we identify two different effects that drive subjects' opportunistic behavior.

Keywords: Common-pool resources; Experiment; Non-Cooperative Games; Uzbekistan; Water.

JEL classification: Q25, C72; C93, H41.

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1. Introduction

Uzbekistan is a double-landlocked, arid country which depends heavily on irrigated agriculture. The agricultural sector is dominated by state-funded programs designed to ensure cotton and wheat production by ordering that 85 percent of cultivated acreage is devoted to these two crops (Guadagni et al., 2005). Because of the dry climate, almost all cultivated land, including that used for wheat and cotton, is irrigated. Water shortages that can significantly reduce production are becoming more frequent and severe, and threat to undermine this economic sector, which accounts for 24 percent of the country's GDP. In addition, the obsolete water management system, created for collective farms during the Soviet time, emphasizes water scarcity. In particular, both the irrigation network and water policies concentrate on output instead of water use efficiency and environmental sustainability. An analysis of individual strategic behavior in allocating water resources is, hence, necessary in this particularly arid region. This study helps to identify potential solutions for the inefficient provision of water, as well as to prevent the devastating environmental damages that could result from a future depletion of the country's water resource.

In this paper we investigate how water use in the region would be affected by different policy mechanisms. We specifically develop three scenarios to characterize different policy approaches: the baseline (or benchmark case), the penalty and the bonus scenario. The baseline case illustrates settings in which subjects do not face any regulatory policy. The penalty scenario, however, punishes those subjects who overuse the resource beyond their allocated amount, while the bonus scenario, by contrast, rewards subjects who conserve water. We first examine whether farmers' actual use of the resource approaches our theoretical predictions and, in addition, we identify if the penalty and bonus mechanisms lead to more efficient levels of appropriation than the baseline scenario. Our goal is to experimentally evaluate the effectiveness of these two alternative mechanisms for eliciting more cooperation in a common-pool resource dilemma.

We first analyze a non-cooperative game in which players strategically select their appropriation levels and identify the theoretical prediction for both the Nash equilibrium of the game and the socially optimal use of water. Second, we describe the experiment we conducted in Uzbekistan, and we compare our theoretical predictions with the experimental observations. The participants of the experiment were farmers from the water-scarce Djizzak region of Uzbekistan who regularly face water shortages. To the best of our knowledge this is the first experiment in Uzbekistan analyzing farmers' strategic behavior regarding water management.

Our results suggest that farmers perceive water as a common-pool resource, and that they tend to over-consume the total available stock. This overuse is emphasized when the total stock becomes more scarce (low precipitation), a common feature in Uzbekistan. Uzbek farmers' overuse can also be explained by the previous Soviet era command-administrative system, which focused only on increasing agricultural output without considering water use efficiency, thus emphasizing their over-consumption of water. When no policy intervention is considered, we identify two main effects which influence farmers' decision to overuse the resource, which we refer as the "optimistic" and "fear" effects. First, the "*optimistic*" effect arises when farmers increase their current water consumption after observing an abundant stock in previous periods, even if the currently available stock is scarcer than in the past. Second, the "*fear*" effect emerges when a low stock in the current period triggers higher appropriation levels, as a tool that farmers use to insure themselves against perhaps even more severe shortages later in the season. The experimental results also show that the penalty and bonus mechanisms reduce appropriation relative to the baseline case, helping in the conservation of the resource and, as a consequence, ameliorating the presence of the above effects.

Our paper contributes to a current discussion among water specialists in Uzbekistan about the benefits of introducing a bonus mechanism to reward farmers for their efficient use of water resources. The above results indicate that a government concerned about efficient water use should indeed consider the implementation of penalties and/or bonuses. Our findings indicate that these policies are effective at reducing individual appropriation levels relative to the benchmark case. Penalties and bonuses also ameliorate the optimistic and fear effects that our experiment identifies when policies are absent, ultimately reducing the overuse of the resource.

The structure of the paper is as follows: section 2 offers a literature review, section 3 develops the model and provides a theoretical analysis for the three different scenarios, section 4 describes the experiment, while section 5 analyzes the results. Finally, section 6 concludes.

2. Literature Review

Two different approaches, cooperative and non-cooperative models, are frequently used in theoretical and experimental studies in order to examine common-pool resources (CPR) dilemmas. Dinar and Wolf (1997) and Dinar (2004) use a cooperative analysis, whereby agents collectively decide the water use for the group, and focus on how to promote cooperation. In particular, while Dinar and Wolf (1997) discuss the conditions for cooperative regional arrangements, Dinar (2004) studies different real-life examples. Our paper complements this research, by studying farmers' strategic behavior in their individual use of irrigation water in Uzbekistan. Unlike these papers, we analyze the effectiveness of commonly recommended policies, such as penalties and bonuses, in protecting the CPR.

Several authors in the field of experimental economics have used non-cooperative models to study group behavior in a CPR. In particular, they experimentally examine the impact of diverse institutions on behavior, such as introducing uncertainty about the resource size, allowing communication among participants, and embodying sanctions and endogenous rule making (Ostrom, 2006 and Ostrom 2011). Our paper contributes to this experimental literature by analyzing how actual farmers from a particularly arid region respond to policies that help to reduce the overexploitation of the commons.

Abbink et al. (2005) conduct a laboratory experiment that investigates the regional negotiation between Kyrgyzstan, Uzbekistan and Kazakhstan over water (from the shared Syr Darya river) by imitating the strategic environment in which these countries bargain. The experimental results indicate that cooperation rarely arises, and that it becomes especially difficult in low-water years. Our paper also studies cooperative behavior assuming complete information of the resource size but, unlike Abbink et al. (2005), we examine farmers individual use of water (rather than countries' negotiations), and allow for different stocks. In addition, our paper explicitly examines tools that help ameliorate free riding behavior.

Walker et al. (1990) also study group behavior in an experiment with limited access to CPR. Their experimental results indicate that the pattern of individuals' decisions does not converge to the Nash equilibrium after several rounds of interactions. Specifically, subjects increase their appropriation levels until their payoffs sharply decline, and then reduce them until payoffs rebound. Our paper hence extends their results to settings in which the stock's abundance is exogenously modified in every period. Indeed, our experimental results provide evidence of a similar behavior, in which subjects appropriate more than the Nash and the socially optimal level.

Rapoport and Au (2001) also analyze a CPR, but from a theoretical and experimental stand point, assuming uncertainty about the resource size and use bonus and penalty mechanisms.[4] Their experimental results show that both treatments significantly reduce the use of the resource use. Similarly, we consider both policies but, rather than analyzing their effects on the behavior of undergraduate students as in Rapoport and Au (2001),[5] we examine their effect on farmers who frequently make similar strategic decisions about their water use in their daily interactions. Our findings also indicate that penalty and bonus mechanisms reduce the appropriation level relative to the baseline case. However, our results suggest that the conservation effect of bonuses identified by Rapoport and Au (2001) remains relatively constant when bonuses become more salient.[6] Indeed, the average payoff in our experiment was equivalent to a farmer's day salary in Uzbekistan and yet, the reduction in overuse we found for Uzbekistan is similar to that in Rapoport and Au (2001). From a policy perspective, our results therefore suggest that, while small bonuses are effective at reducing water overuse, large bonuses would not necessarily affect farmers' behavior.

Finally, Casari and Plott (2003) develop an experiment to study the nature of enforcement rules (inspection and sanctions) in a CPR where individuals monitor each others' actions.[7] The monitoring mechanism considerably promotes an efficient use of the resource, especially when sanctions are larger. This coincides with our experimental results which indicate that sanctions, such as a penalty, can increase efficiency.

[4] Rutte et al. (1987), Budescu et. al. (1992) and Rapoport et. al. (1994) also examine a CPR under uncertainty about the size of the initial stock. Similarly, Apesteguia (2006) develops an experiment analyzing a CPR game where the stock level is unknown.

[5] Their experiment was conducted at the Chinese University of Hong Kong.

[6] The mean payoff per participant (in U.S. dollars) was $16.8 in Rapoport and Au's experiment B (bonuses).

[7] The experiment structure is based on Italian Alps' institutions that have been used for centuries.

3. Model

Baseline Scenario

We use a single-stage, non-cooperative, *n*-person CPR game in which a group of N players can appropriate a common-pool resource whose exact size is exogenously given. Every player i $(i \in N)$ chooses a nonnegative amount x_i where $x_i \in [0,1,...,10]$.[8] The payoff function of player *i* is given by:

$$U(x_i) = \left(\frac{x_i}{X}\right)[aX - bX^2] + c(W_r + RW_P - X) \qquad (1)$$

where $X = \sum_{i=1}^{N} x_i$ denotes the total level of appropriation of the resource. The first term of the payoff function represents the benefits accruing to player i which depend on his individual appropriation, x_i, and the other players' appropriation levels. Similar to Walker et al. (1990), Hackett et al. (1994), Gardner et al (2000), Casari and Plott (2000), and Apesteguia (2006), we use a quadratic production function to calculate the individual payoff as a proportion of the total group appropriation level of the resource. This particular functional form implies diminishing returns to production, describing, for instance, a reduction in farmers' yields when the group appropriation of water is very high. We do not explicitly assume costs for the use and extraction of water. More precisely, these costs are captured by the parameter *b*. In addition, *a* and *b* are positive parameters (*a>0* and *b>0*) where *b*∈(0,1) and *a>b*.

The second part of the payoff function represents player *i*'s benefits/disutility from the stock availability and stock use from cooperation between players over the resource appropriation. We assume that the total stock consists of permanent and additional stocks. The permanent stock represents the amount of water in the river, W_r. The additional stock, RW_P, represents water accumulated from precipitation. *R* is the level of precipitation and it is a random

[8] The individual action space is limited to the interval between 0 and 10 to avoid large negative payoffs.

variable, where $R \in [0,1]$, W_P is the maximum amount of precipitation water (e.g., 50 units), and *c* is a positive constant. Hence, the second element of the payoff function represents player *i*'s disutility if the group overuses the total available stock, $W_r + RW_P < X$, or his benefits if the group underuses the total available stock, $W_r + RW_P > X$.

Summarizing, the individual payoff depends on the individual appropriation level, x_i, group appropriation of the CPR, *X*, and W_p. Player *i*'s best response function is a linear function of the appropriation level of all other players, X_{-i},

$$x_i(X_{-i}) = \frac{a-c}{2b} - \frac{1}{2}X_{-i} \qquad (2)$$

where $X_{-i} = \sum_{j \neq i}^{N} x_j$. In addition, $x_i(X_{-i})$ decreases in the total use of the resource by other players. Since, in our experiment we use the same parameters values as in Walker et al. (1990), (*a*=23, *b*=0.25 and *c*=5), expression (2) can, hence, be expressed as:

$$x_i = 36 - \frac{1}{2}X_{-i} \qquad (3)$$

Given that in our model players are symmetric, the Nash equilibrium is obtained by solving (2) for all players $i \in N$, i.e. $x_i^{NE} = \frac{a-c}{(N+1)b}$. Note that the equilibrium appropriation level, x_i^{NE}, decreases in the group size, *N*. Substituting the same parameter values as in the experiment yields $x_i^{NE} \approx 7$. The socially optimal appropriation level that maximizes group payoffs, is $x_i^{SO} = \frac{a-c}{2Nb}$ and, hence, $x_i^{SO} \approx 4$. This scenario and its theoretical predictions establish a benchmark to investigate the penalty and bonus mechanisms in a CPR environment.

Penalty Scenario

The penalty model induces a reduction in the payoff of the player who selects $\bar{x}$, the highest appropriation level of resource. In particular, his payoff function is similar to the base case model, but the third term includes a penalty component:

$$U_i^P(\bar{x}) = \frac{\bar{x}}{X}[aX - bX^2] + c\big(W_r + RW_p - X\big) - \big[U_i(\bar{x}) - U_j(\underline{x})\big] \quad (4)$$

where $i \neq j$, $U_i(\bar{x})$ represents player *i*'s utility in the baseline scenario when he chooses the highest appropriation level $\bar{x}$, while $U_j(\underline{x})$ is player *j*'s utility when he selects the lowest level of appropriation, $\underline{x}$, among all the other players. When player *i* chooses the highest appropriation level, he then suffers a penalty measured by $\big[U_i(\bar{x}) - U_j\big(\underline{x}\big)\big]$, and his utility coincides with player *j*'s payoff from selecting the lowest appropriation level.

$$U_i^P(\bar{x}) = \underbrace{\frac{\bar{x}}{X}[aX - bX^2] + c\big(W_r + RW_p - X\big)}_{U_i(\bar{x})} - \big[U_i(\bar{x}) - U_j\big(\underline{x}\big)\big] = U_j\big(\underline{x}\big) \quad (5)$$

Bonus Scenario

We next study a bonus mechanism which induces players to select lower appropriation levels and promotes the efficient use of the resource.[9] Several studies provide evidence that a bonus mechanism generates economic incentives for reducing appropriation levels eliciting cooperation.[10] However, choosing a lower level of appropriation reduces a player's competitiveness relative to other players. Nonetheless, his lower appropriation might be compensated with a bonus if he chooses the lowest appropriation level, $\underline{x}$.

[9] Note that we do not specify how bonus can be funded. It may be provided by some government agency or financed by taxes.
[10] See Rapoport and Au (2001), McCusker and Carnevale (1995), Yamagishi (1986), and Komorita and Barth, (1985).

Specifically, the payoff function of the player selecting the lowest appropriation level, $\underline{x}$, is similar to that in the baseline model, but it now contains a bonus component:

$$U_i^B(\underline{x}) = \frac{\underline{x}}{X}[aX - bX^2] + c(W_r + RW_p - X) + [U_j(\bar{x}) - U_i(\underline{x})] \quad (6)$$

where $i \neq j$, $U_j(\bar{x})$ denotes player j's utility in the baseline scenario when he chooses the highest appropriation, $\bar{x}$, among all players, whereas $U_i(\underline{x})$ is player i 's utility when he selects $\underline{x}$. Hence, his utility reduces to the payoff that player j obtains from selecting the highest appropriation level $\bar{x}$:

$$U_i^B(\underline{x}) = \underbrace{\frac{\underline{x}}{X}[aX - bX^2] + c(W_r + RW_p - X)}_{U_i(\underline{x})} + [U_j(\bar{x}) - U_i(\underline{x})] = U_j(\bar{x}) \quad (7)$$

4. Experiment

In this section, we examine whether farmers behave as predicted by our theoretical model, and how their water use responds to penalties and bonuses, relative to the (unregulated) baseline scenario. In particular, our experiment was conducted among the farmers in the town of Dashtobod, Djizzak province, Uzbekistan. This province borders with Kazakhstan in the north, the Uzbek province of Tajikistan in the south, the Syrdarya in the east, the Samarkand province in the southwest, and the Navoi province in the west. The climate is typically continental, with dry and hot summers and mild winters. The mean annual precipitation for the province is relatively scarce (230 mm), occurring generally in the winter-spring seasons.[11] This area is dominated by a flat extensive plain that can be used for agricultural production only through irrigation. Most famers, however, exhibit water-deficit problems due to a poor management and the declining technical conditions of the irrigation infrastructure. Figure 1 shows the irrigation

[11] As a reference, note that this rainfall is similar to that in the San Diego area in California with an annual precipitation of 200 mm.

system map for this region. The water is diverted from the Syr Darya river that is then lifted through several pump-stations in the northern Syrdarya province, then distributed through the Southern Mirzachul Canal (SMC), and finally through three canals: Djizzak Machinery (DM) Canal N°1, N° 2 and N° 3 to local Water Users Associations (WUAs). Farmers are not charged for irrigation water but they pay a fixed annual fee for delivering water and maintaining the irrigation canal based on hectares of land irrigated. However, water volume authorized to their farms depends on the types of crops they cultivate.

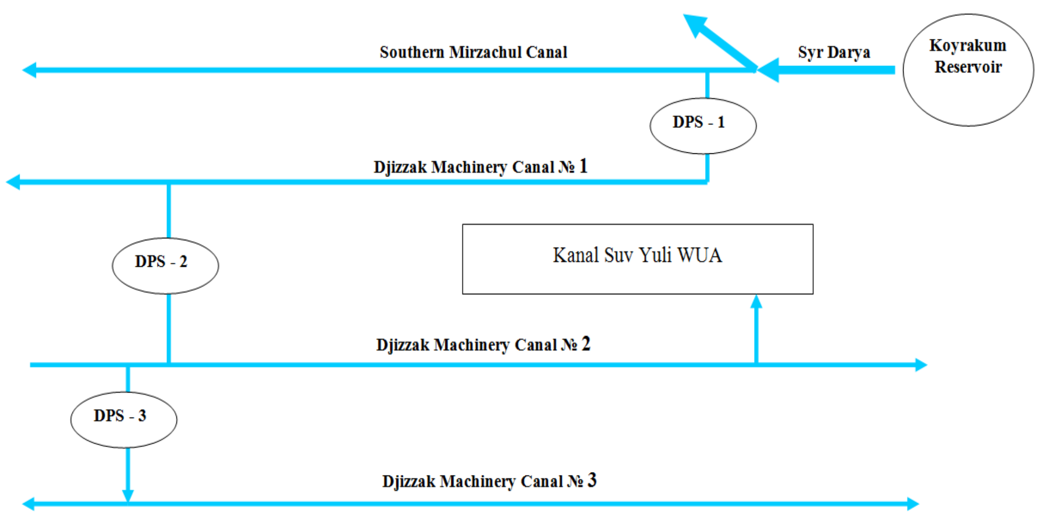


Figure 1. Irrigation System Map.

All subjects in the experiment are members of the *Kanal Suv Yuli* WUA. This association consists of 31 farms ranging between 35 and 109 ha. The total area of the WUA is 1,853 ha. The land in this WUA is mainly used to wheat (60%) and cotton (30%), leaving the remaining 10 percent to crops like onion, corn and melon.[12] The total length of the canals in this WUA is 2,200 meters. Water used for irrigation in these farms is lifted by a pump-station and distributed through the DM- Canal N° 2- Canal N° 1.

[12] These crops are not only used for home consumption, but are also sold at markets to generate additional income.

The experiment consists of the three scenarios: baseline, penalty, and bonus - each played for 15 rounds.[13] Ten farmers from the WUA in Djizzak region were recruited by the WUA to participate in the experiment.[14] Each subject received a pen, a set of instructions and several record sheets (included in the appendix). Subjects had one record sheet for the trial game and three record sheets for the baseline, penalty and bonus cases. Before the experiment began, the experimenter asked subjects to read the instructions. After reading the instructions, he addressed any concerns that subjects may have. Two periods of trial game were played and participants were asked to keep their scores on the trial record sheet. The objective of the trial game was to make sure that subjects understood the rules of the game.

Before the experiment began, each subject was assigned a random ID number consisting of three digits (for example, 101 or 329) which did not affect the player's order of move or his payoffs during the experiment. The last digit was actually determining the subject's ID and helped us to keep track of his actions and payoffs.[15]

At the beginning of every period, the experimenter determined the total stock of the available resource, which included both permanent and additional supply. The permanent stock represents the amount of water in the river for irrigation, i.e. W_r, which we assume to be constant and equal to 50 units in each period. The additional stock represents the precipitation, W_p, and varies in each period. The maximum amount of additional stock is 50 units. At the beginning of each period, before subjects were allowed to make any decisions, the experimenter announced the amount of additional stock. Specifically, he randomly chose a number between 0 percent and 100 percent with increments of 10 percent. For instance, if the experimenter picked 20 percent of

[13] Note that the typical time horizon in this type of experiments is between 10 and 25 periods; see, e.g., Ostrom et al. (1994), Herr et al. (1997), Keser and Gardner (1999), and Walker et al. (2000).
[14] Subjects were seated around a large table. It was not possible to arrange an individual desk for each player.
[15] We assigned a three-digit number, rather than a one-digit number, in order to avoid that players inferred that the one-digit number they received had a strategic position in the experiment.

additional stock, then the total amount for a given period is 60 units (50 + 50*0.2 = 60).[16] After the total stock is announced, subjects made a choice by writing a number between 0 and 10 on their record sheets, which represents his appropriation of water in the current period. Participants independently and simultaneously chose their appropriation level, x_i. Communication between players was not allowed. Subjects were asked to cover their numbers and put down their pens after they wrote a number on their record sheets.[17]

All subjects faced the same private payoff function. The experimenter publicly announced the total amount of resource used by the group, all subjects' actions and their corresponding payoffs in each period. Subjects were then asked to proceed to the next period, where a new total stock of available resource was determined, and subjects were asked to choose the appropriation level between 0 and 10 again. When the 15th round was over, the experimenter summed up subjects' payoffs for all 15 periods and publically announced the total payoffs to each subject.[18]

After the 15 periods of the baseline, subjects participated in two more 15 rounds with the penalty and bonus scenarios, respectively. The experimenter distributed new instructions for the penalty and bonus games and asked subjects to read them. In the penalty (bonus) game, the player who selected the highest (lowest) appropriation level is penalized (rewarded, respectively). [19]

[16] Since this information was publically announced, it became common knowledge among all players.

[17] Once all subjects wrote their numbers on a record sheet, the experimenter asked each subject to say their number aloud. While subjects announced their numbers, the second experimenter typed them into an Excel file to calculate players' payoffs.

[18] The player with the highest total payoff received a monetary prize of 15,000 Uzbek Soums (currency in Uzbekistan), equivalent to US$ 8.69 according to the 2011 official exchange rate, i.e., 1,727 Uzbek Soums per dollar.

[19] The penalized (rewarded) subject was, hence, determined endogenously by comparing his appropriation level to those of the other N-1 subjects in the group. If several subjects were tied at the maximum (minimum) level of appropriation, then all of them were penalized (rewarded) by the same amount.

After all three scenarios were played, the experimenter summed up all points. The three subjects with more total points received grand prizes of 15,000 UZS (US$8.68, first place) and 10,000 UZS (US$ 5.79, second and third places). All subjects received a fixed amount of 20,000 UZS (US$ 11.58) for their participation in the experiment after taking a short final survey (see appendix) asking participants about their socio-economic background. Average earnings per subject were 28,000 UZS (US$ 16.21) varying between 20,000 and 50,000 UZS (i.e. US$ 11.58 and US$ 28.95).[20]

Table 1. Descriptive statistics from survey

Variable	Mean	Standard Deviation	Min	Max
Age (year)	41.40	11.13	21.00	50.00
Years in Agriculture (year)	20.60	10.18	5.00	31.00
Family Size (people)	6.60	1.26	4.00	8.00
Farm Size (ha)	87.56	43.18	14.80	180.00
Crop planted:				
- Cotton	1.00	0.00	1.00	1.00
- Wheat	1.00	0.00	1.00	1.00
- Corn	0.70	0.48	0.00	1.00
- Onion	0.50	0.53	0.00	1.00
- Melon	0.40	0.52	0.00	1.00
Crop Distribution on Farm (ha):				
- Cotton	38.13	21.52	5.00	90.00
- Wheat	41.15	24.98	6.50	90.00
- Corn	5.18	9.27	0.00	30.00
- Onion	2.55	6.20	0.00	20.00
- Melon	0.55	0.93	0.00	2.50
Location on Irrigation Canal:				
- Beginning	0.20	0.42	0.00	1.00
- Middle	0.40	0.52	0.00	1.00
- End	0.40	0.52	0.00	1.00

Table 1 shows the descriptive statistics obtained from the survey. All participants are male farmers, 41 years old on average, and ranging from 21 to 50 years old. On average they

[20] The experiment lasted for 3 hours and 30 minutes including: instructions, 2-periods trial game, the experiment and the final survey. It started at 7:30 am and finished at around 11:00 am. The average daily temperature in this region is 35-40°C (95-104F) in July, the month in which the experiment was conducted. We provided subjects with soft drinks and snack.

have 21 years of experience in agriculture (ranging from 5 to 31 years), and the average family size is approximately 7 people. The average farm size is 88 ha. These farmers specialize in cotton and wheat production with a small portion of land devoted to horticultural crops and home gardens for family production. [21]

The survey also reveals that farmers are knowledgeable about their neighbors, especially about the ones located close to them. [22] In particular, farmers know how much water their neighbors need (90 percent), what they plant (100 percent), and the size of their planted area (100 percent). Developing a game with complete information is, hence, appropriate for such an environment. Only 20 percent of farmers indicate that they obtain the necessary volume of water. Farmers are not specifically charged for the amount of irrigation water they use, but instead pay a fee to the WUA based on the hectares of their property (10,000 UZS/ha per year in 2011). 90 percent of them report having conflicts with their neighbors because of water, and 90 percent of them describe conflicts with the WUA about water distribution.

Farmers also indicate that a penalty mechanism is incorporated in the bylaw of the WUA. They believe the WUA punishes farmers for overusing water in the form of allowing them less time to irrigate (a reduction of water supply) during next period. Nonetheless, the WUA imposes no monetary fees for water overuse, nor it provides bonuses to induce. Furthermore, the majority of the farmers (90%) indicated that they would get involved in illegal activities to obtain the volume of water they need for their crops (by irrigating more time than they are allowed, breaking water gates, etc.), indicating that farmers are desperate for water and have to deal with water shortages on a regular basis.

[21] They specifically plant on average 38 ha of cotton and 41 ha of wheat, with these crops ranging from 5 to 90 ha and 7 to 90 ha, respectively. 40-70 percent of farmers also produce corn, onion, and melon. However, the planted area is much smaller for these crops compared to cotton and wheat. In particular, corn is grown on average on only 5.18 ha, onion on 2.55 ha and melon on 0.55 ha.

[22] These and other results from the survey, not reported on table 1, can be provided by the authors upon request.

5. Results

In this section, we separately present our experimental results for the baseline, penalty, and bonus scenarios and show how the behavior of the farmers is affected by different water management rules. In addition, we investigate whether subjects' choices approach to the equilibrium appropriation level x_i^{NE} described in our theoretical predictions or, instead, approximate to the socially optimal appropriation for the group x_i^{SO} also analyzed in Section 3.

Table 2 shows the experimental results for each of the three scenarios as well as the overall appropriation levels. The table provides summary statistics for the available stock and for group appropriation. In particular, the last three rows identify the total amount of stock, total appropriation, and appropriation rate (as a percentage of the total stock). In the *baseline* scenario, the available stock varied between 50 and 100 units and its average was 79 units during the 15 rounds of interaction. The average level of appropriation by all farmers in the group was 79.4 units per period, and ranged between 63 and 92 units. During this scenario, subjects chose to appropriate 100.5 percent (1191 of 1185 units) of the available stock.

Table 2. Experimental results

Indicators	Baseline	Penalty	Bonus	Overall
Resource Stock (water units/period)				
Average	79	82	77.3	79.44
Standard Deviation	14.65	16.67	15.57	15.42
Min	50	55	55	50
Max	100	100	100	100
Group Appropriation (water units/period)				
Average	79.4	52.27	46.73	59.47
Standard Deviation	9.2	11.52	14.39	18.53
Min	63	35	26	26
Max	92	71	77	92
Overall Periods (water units)				
Total Resource Stock	1185	1230	1160	3575
Total Appropriation	1191	784	701	2676
Appropriation Rate (%)	100.51%	63.74%	60.43%	74.85%

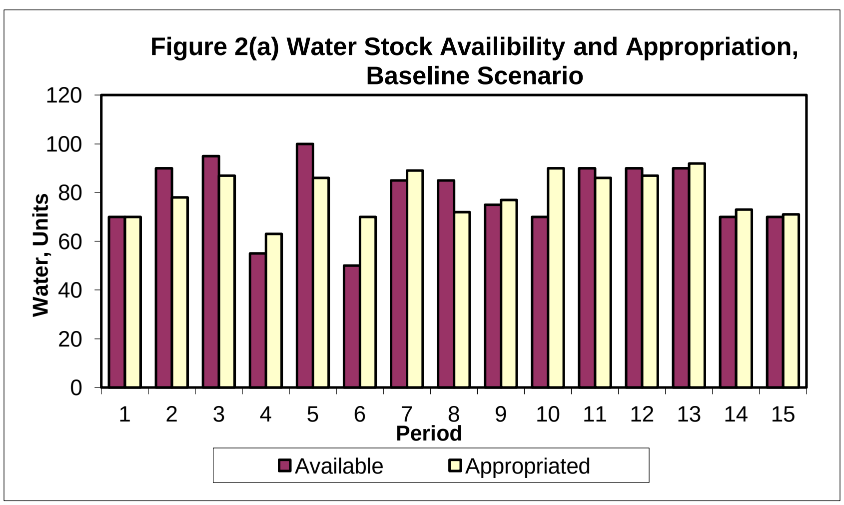
In the *penalty* scenario (third column), the available stock varied between 55 and 100, with an average of 82 units per period, which is a 3.8 percent higher than the available stock at the baseline scenario.[23] Ranging between 35 and 71 units, the average level of group appropriation is 52.3 units per period in the penalty scenario, which is a 34 percent lower than in the baseline case. Furthermore, the analysis of variance (ANOVA) and the Mann-Whitney test indicate that there is a statistically significant difference in average levels of appropriation by group between these two scenarios [$F(1,28)=50.81$; $p<0.001$] and [$z=4.44$; $p<0.001$], even after eliminating the observations of the first three or four periods in both scenarios [$F(1,22)=36.05$; $p<0.001$] and [$F(1,20)=39.12$; $p<0.001$].[24] The resource use by the group is hence lower for the penalty than for the baseline scenario, dropping from 1191 to 784 units. Indeed, during the 15 periods of the penalty scenario, subjects decide to appropriate only 64 percent of the available stock (784 of 1230 units). Even though the level of the resource availability is higher in this scenario, subjects consume less as a group than in the baseline case.

In the *bonus* scenario, the available resource stock varied between 55 and 100 units, and its average was 77.3 units per period.[25] Ranging between 26 and 77 units, the average appropriation level of water use by the group is 46.7 units per period, which is a 41.1 percent lower when compared to the baseline case.[26] In particular, during the 15 periods of the bonus

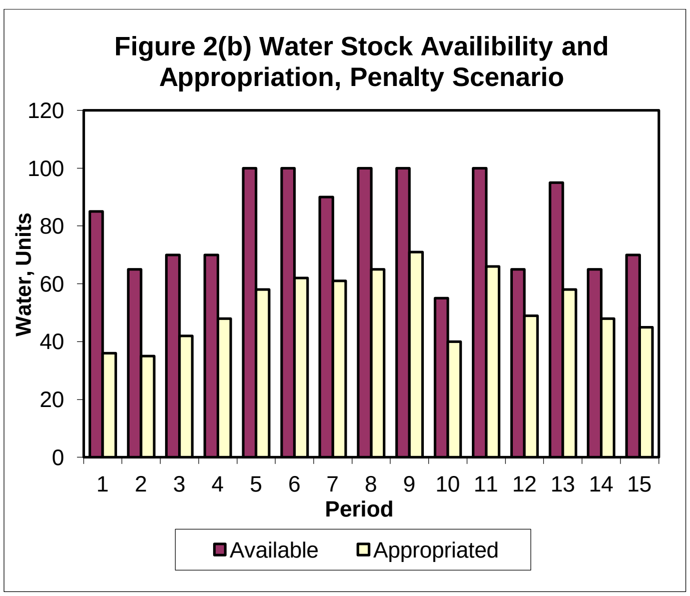
[23] The ANOVA suggests that there is no significant difference in the resource availability between two scenarios [$F(1,28)=0.27$; $p=0.6048$].
[24] We eliminate the observations of the first three-four periods to avoid the effect of subjects' learning behavior under new rules at the beginning of the experiment.
[25] This is lower than in the baseline and penalty cases, but an analysis of variance shows that the difference in available stock between the penalty and bonus scenarios is not significant [$F(1,28)=0.09$; $p=0.7650$]. The amount of available resource stock is lower on average by 5 units in the bonus scenario compared to the penalty scenario, but is not statistically significant either [$F(1,28)=0.63$; $p=0.4348$].
[26] Furthermore, the ANOVA shows that there is a significant statistical difference in average levels of appropriation between these two scenarios [$F(1,28)=54.84$; $p<0.0001$]. After eliminating the observations in the first three or four periods in the baseline case, the test indicates that there is still a significant difference [$F(1,22)=38.15$; $p<0.0001$] and [$F(1,20)=39.21$; $p<0.0001$].

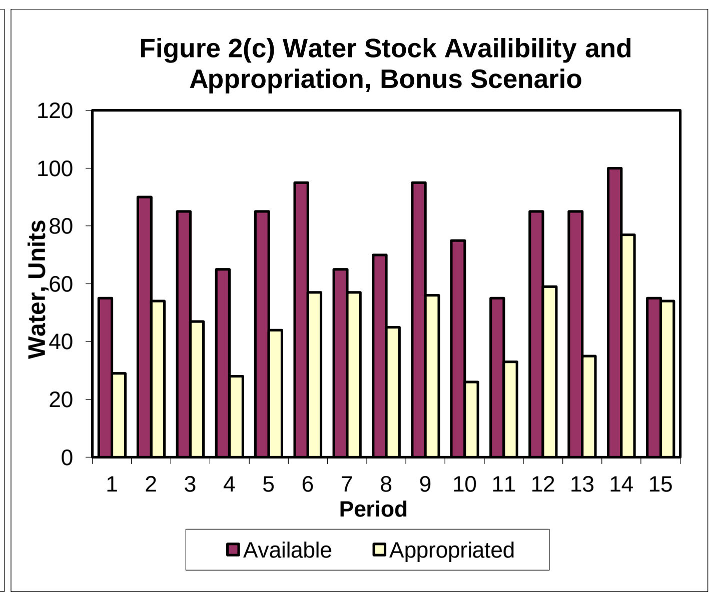
game, subjects consume 60 percent of the available stock (701 of 1160 units), an appropriation rate similar to that in the penalty scenario (64 percent).

Figures 2(a-c) compare the stock availability and group appropriation (in units) during the 15 rounds of the baseline, penalty and bonus scenarios. Specially, figure 2(a) indicates that in the baseline scenario subjects overuse the resource stock eight times (in the 4th, 6th, 7th, 9th, 10th, 13th, 14th, 15th periods). Furthermore, the third period contains a high level of available stock that leads subjects to overuse the resource in the subsequent (fourth) period, despite not overusing the resource during any of the previous periods. This behavior can be explained by the fact that subjects become more optimistic about the stock availability in the fourth period. This "*optimistic effect*" can potentially explain why an underuse of the resource in one period of relatively abundant stocks leads to an overuse of the resource in future periods in which the stock was scarcer, suggesting that players did not fully internalize the reduction in the stock availability that occurred between these time periods. A similar behavior emerged in the sixth and ninth periods.



In addition, during the 15 rounds of the baseline scenario subject choices provide evidence of a pulsing pattern in which individuals appear to increase their level of resource appropriation until their payoffs are significantly reduced. One such an example arises in the sixth period where, despite the available stock lies at its lowest level (50 units), 20 percent of subjects continue to consume as in the previous period (where the available stock was at its highest possible level of 100 units) and 30 percent decide to choose the maximum appropriation level. Importantly, these subjects alone (50 percent of the total group) appropriate the entire available stock (50 units) ultimately leading to an overuse of the resource. As a consequence, their actions induce nonnegative profits on all subjects. This behavior can be interpreted as a "*fear effect*," where subjects might be afraid of not obtaining enough water in the current period when the resource is scarce. Finally, note that the experiment resembles the conditions in which farmers interact on a daily basis (with periods of water scarcity and uncertainty). Their observed behavior in the experiment can, hence, be interpreted as describing their actual water consumption patterns.





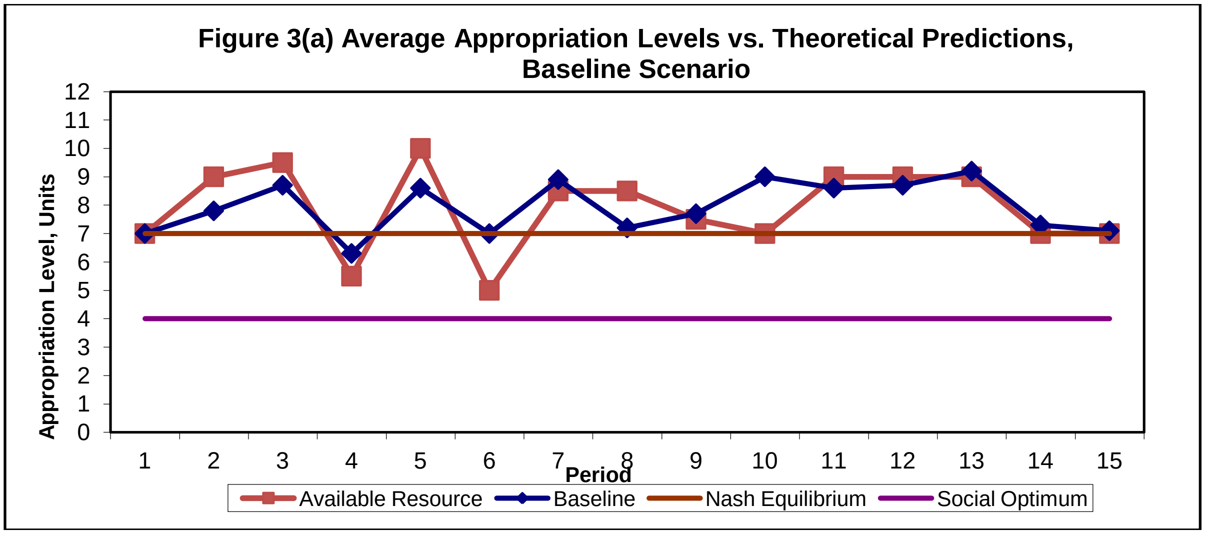
Figures 2(b) and 2(c) display the resource stock and group appropriation during the 15 rounds of the penalty and bonus scenarios. Interestingly, there is no overuse of the stock at any single period in these two scenarios. This suggests that imposing penalties and bonuses induces farmers to appropriate less of the available resource than in the baseline scenario. Therefore, the experiment shows that the "optimistic effect" is absent in the penalty and bonus scenario, since farmers do not overuse the resource after experiencing a significant decrease in the available stock, as that occurring in period 4. Similarly, the "fear effect" (describing a substantial overuse of the resource when the stock is particularly scarce) does not emerge in the penalty and bonus scenarios given that, as reported above, the resource is not overused in these settings regardless of the precise level of the stock.

In the bonus scenario, individuals can be divided into two categories. In the first category, subjects are interested in obtaining a bonus by preserving the stock. By contrast, the second category includes subjects who are willing to consume the entire stock. For example, while one subject (ID #322) focuses on receiving a bonus by selecting a zero level of appropriation in 10 out of 15 periods, another player (ID #748) seems to be uninterested about the bonus and selects the maximum level of appropriation (in 14 of 15 periods).[27]

Comparison with theoretical predictions. We next compare the observed appropriation levels with the theoretical predictions of section 3. For the baseline scenario, figure 3(a) shows the individual average appropriation levels at each period, and the theoretical predictions, i.e. Nash equilibrium (NE) and socially optimal equilibrium (SO). For completeness, the figure also includes the stock level for all 15 periods. Figure 3(a) suggests a significant difference between the average appropriation level, the NE and the SO. Subjects' average appropriation level is at and above the NE level at the beginning of the experiment (from 1st to 8th periods, except for the 4th period). This trend, however, decreases rapidly at the last two periods, where appropriations levels converge towards the NE.

[27] Other players instead, mixed their appropriation decisions. For instance, one player (ID #117) selects a zero level of appropriation at the first round of interaction and randomizes between 0 and 10 units for the rest of the game.

Only 8 percent of all subjects' decisions coincide with the NE. The ANOVA indicates that there is indeed a significant difference between the average appropriation level and the NE theoretical prediction [F(1,28)=15.65; p=0.0005].[28] On average, subjects also appropriate above the socially optimal level during all periods. An analysis of variance and the Mann-Whitney test indicate that the average appropriation level is statistically different from the social optimum at any statistical level [F(1,28)=274.96, p=0.0001] and [z=4.989, p=0.0001].



For the penalty scenario, figure 3(b) depicts average appropriation levels for each period, and compares them with the NE, the SO and the available stock. Subjects' average appropriation lies below the NE, except in the ninth period. In these two periods, the penalty mechanism induces subjects to appropriate on average the NE. Overall, however, only 11 percent of all individual decisions are consistent with the NE predictions.[29] The average level of appropriation in all periods is above the social optimum, except for the first, second and tenth periods. While the penalty mechanism compels subjects to choose the socially optimal level in these three

[28] The Mann-Whitney two-sample test rejects the null hypothesis of equal population medians at any significant levels [z=3.783, p = 0.0002]. We, therefore, can conclude that on average subjects' choices are different from the NE.

[29] Specifically, an analysis of variances indicates that there is a significant difference between the average appropriation level and NE [F(1,28)=35.56; p<0.001]. Furthermore, the Mann-Whitney test rejects the null hypothesis of equal population medians at any statistical level [z=-4.323; p<0.001].

periods, only 11 percent of all choices coincide with the socially optimal level. Indeed, an analysis of variance and the Mann-Whitney test indicates that the average appropriation level is statistically different from the social optimum at any statistical level [F(1,28)=17.02, p=0.0003] and [z=3.378, p=0.0007].

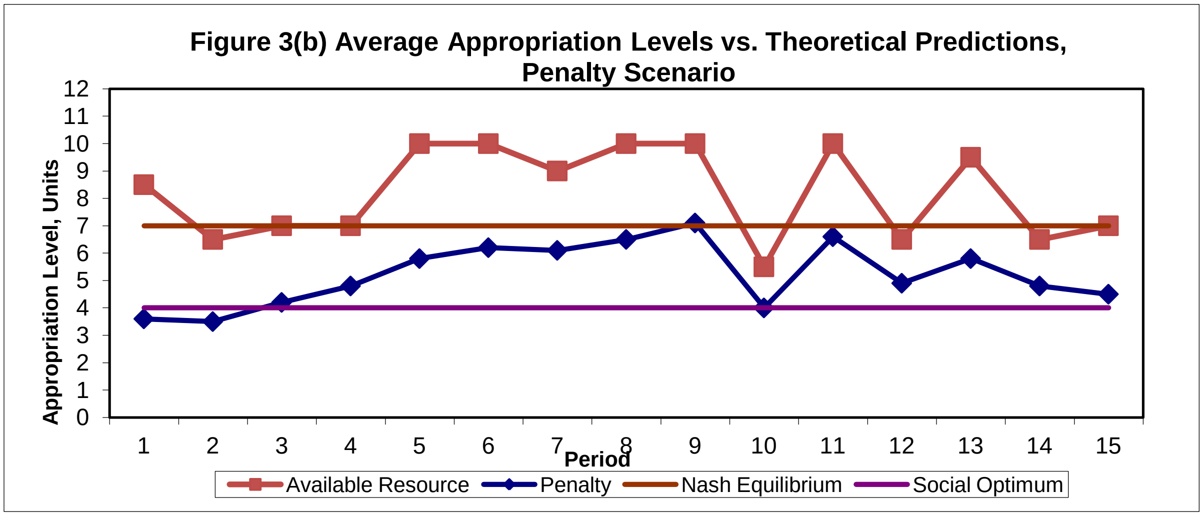
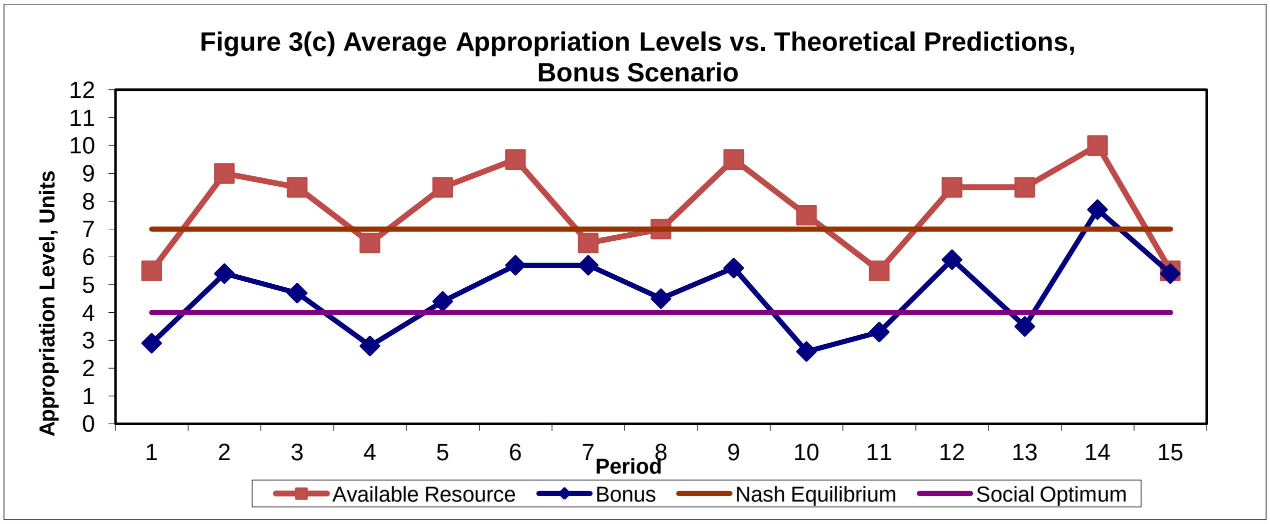
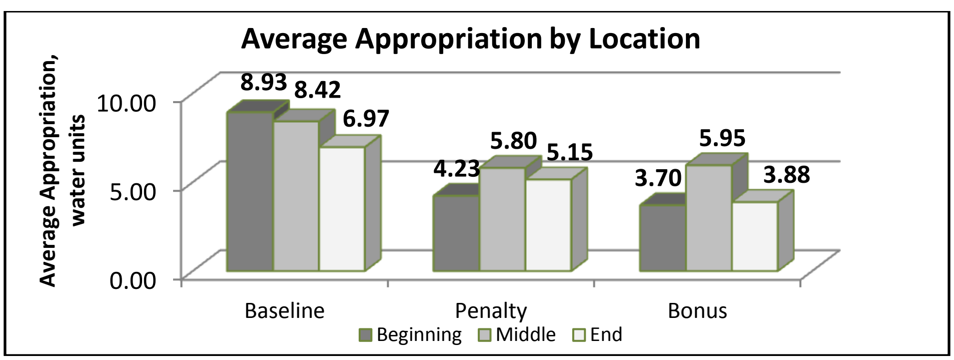


Figure 3(b) also illustrates that the average appropriation level falls below the available stock, i.e. underuse of the resource. Similar to the baseline case, the appropriation level in the penalty scenario strongly depends on the available stock. Nonetheless, regardless the precipitation level, subjects appropriate substantially less under the penalty scenario than in the baseline case.



Finally, figure 3(c) above indicates that the average appropriation falls below the NE during all periods, except in period fourteenth. The figure also indicates that, unlike the penalty mechanism (which induces subjects to voluntarily appropriate an amount close to the NE), the bonus mechanism does not persuade subjects to appropriate, on average, NE amounts. Indeed, only 5 percent of all decisions in the bonus scenario coincide with the NE predictions.[30] We also observe that average appropriation is lower than the social optimum in one third of periods. Specifically, an analysis of variance and the Mann-Whitney test show that the average appropriation level is statistically different from the social optimum at a 10% significance level [$F(1,28)=3.28$, $p=0.0808$] and [$z=1.663$, $p=0.0963$].

Figure 3(c) also displays the relationship between the average appropriation level and the available stock. Similar to the penalty case, the average appropriation lies below the available stock in all periods, and it decreases relative to the baseline case, suggesting that the bonus mechanism is also effective in conserving the resource. For a better understanding of our results, we next analyze the average appropriation level of the resource based on the subject's actual location within the irrigation system. Figure 4 displays the average appropriation levels for subjects who claimed in the final survey to be located at the beginning, middle and end of the irrigation system for each of the three scenarios.



[30] An analysis of variance and the Mann-Whitney test confirms this finding, since there is a significant difference between the average appropriation level and that under the NE [$F(1,28)=39.19$; $p<0.0001$] and [$z=-4.323$, $p<0.0001$].

In the baseline scenario, subjects located at the beginning of the irrigation system appropriate more than those in the other two locations (i.e., 8.93 units). In contrast, under the penalty scenario, subjects at the beginning of the irrigation system are now the individuals appropriating the least (4.23 units) whereas subjects located in the middle appropriate the most (5.80 units). Finally, the results in the bonus scenario are similar to those in the penalty scenario. These findings make evident that subjects' location within the irrigation system has an impact on their decision. In particular, they suggest that individuals whose crops are located at the beginning of the irrigation system are more sensitive to the introduction of penalty (or bonus) mechanisms that promote conservation than other farmers located at the end of the system.[31]

Econometric Analysis

In this section we examine which factors influence individuals' appropriation levels, including: the stock abundance, since the level of the resource is announced to all subjects at the beginning of the game, and the individual level of appropriation in the previous period, since past decisions can influence current choices (e.g., learning from bad experiences). We also include demographic variables (such as education, years of experience in the agricultural sector, and location on the irrigation system). Hence, individual *i*'s appropriation level at period *t*, x_{it}, is defined as:

$$x_{it} = \alpha + \beta_1 Resource_t + \beta_2 x_{it-1} + \sum_{j=1}^{4} z_j Demographics_i + \varepsilon_{it}$$

where $Resource_t$ is available stock at time *t*; x_{it-1} is an appropriation level of subject *i* at the previous period *t-1*; and $Demographics_i$ contains subject *i*'s education level, his years of

[31] For instance, the introduction of penalties reduces the appropriation levels of farmers at the beginning of the irrigation system by a 53 percent, but only reduces the appropriation level of farmers at the end of the irrigation system in a 26 percent.

experience in agriculture and his location along the irrigation canal. Table 3 presents a description of the above variables.

Table 3. Description of explanatory variables

Variables	Description
Experiment	
x_{it}	Appropriation level of subject *i* at time *t*
x_{it-1}	Appropriation level of subject *i* at time *t-1*
$Resource_t$	Available resource stock in period *t*
Demographic	
Education	1 = Bachelor's degree or above, 0 = otherwise
AgrExprnce	Reported years of experience in agriculture
MidLocation	1 = located in the middle, 0 = otherwise
EndLocation	1 = located at the end, 0 = otherwise
Scenario	
Penalty	1 = penalty, 0 = otherwise
Bonus	1 = bonus, 0 = otherwise

Our first hypothesis states that the individual appropriation level, x_{it}, is lower in the penalty and the bonus scenario than in the baseline case. Our second hypothesis claims that an individual's appropriation level is increasing in the availability of the stock in the current period, and in the individual's own level of appropriation in the previous period.

Since the experimental observations of 10 individuals over 15 periods form a panel data, we first test for autocorrelation over periods and heteroscedasticity between individuals for each of the three scenarios separately and then for all cases combined. Using the Wooldridge test for autocorrelation in panel data, we reject the null hypothesis of no first order autocorrelation in all three scenarios and aggregate dataset suggesting that there is autocorrelation over periods. In addition, the Breusch-Pegan test for heteroscedasticity rejects the null hypothesis of homoskedastic standard errors for the baseline scenario (p=0.0002); but we fail to reject the null hypothesis for the penalty and bonus scenarios (p=0.1546 and p=0.9086, respectively). However, the aggregated dataset of all three scenarios exhibits heteroscedasticity (p=0.0001). Thus, we conclude that the error terms ε's are potentially correlated over periods and heteroscedastic between individuals and, as a consequence, the feasible generalized least-squares estimation (FGLS) is more efficient than ordinary least-squares (OLS) (Cameron and Trivedi, 2009).

Table 4 displays the results using FGLS estimation with the estimates, standard deviations and significance levels. The second column provides the estimation results for the aggregated data from all three scenarios. The results indicate that current appropriation increases by 0.29 units for every additional unit of appropriation during the previous period, suggesting that previous history of play persists to a large extent in future periods. The current available stock also has a positive and statistically significant effect on current appropriation. In particular, the subject's appropriation increases by 0.06 units for every additional unit of available stock. Let us now analyze the effect of demographic variables on the subject's appropriation decisions. First, individual appropriation decreases by 0.25 units if the subject has a bachelor's degree or a higher education attainment. Similarly, the individual level of appropriation increases by 0.03 units for an additional year of experience in agriculture. Nonetheless, the effect of education is not statistically significant. By contrast, the location along the irrigation system has a significant impact on the appropriation decision. Specifically, subjects located in the middle of the irrigation system decide to appropriate on average 0.56 units more than farmers at the beginning or end of the system, while those located at the end appropriate 0.49 units less than individuals at the beginning of the irrigation system.

Table 4. The estimation results of the individual level of appropriation.

Variables (1)	**Aggregat (2)**	**Baseline (3)**	**Penalty (4)**	**Bonus (5)**	**Aggregate with interactions (6)**
$Appropriation_{t-1}$	0.288***	-0.108**	0.371***	0.173**	0.220***
	(0.043)	(0.046)	(0.020)	(0.077)	(0.043)
$Resource_t$	0.057***	0.039***	0.056***	0.053***	0.043***
	(0.006)	(0.009)	(0.002)	(0.008)	(0.011)
Education	-0.248	-0.928***	-0.074	0.368	-0.264
	(0.294)	(0.139)	(0.116)	(0.444)	(0.174)
AgricultExprnce	0.029**	0.045***	0.036***	0.026	0.031***
	(0.012)	(0.010)	(0.009)	(0.033)	(0.012)
MidLocation	0.563	-1.175***	0.683***	2.412**	-0.583
	(0.365)	(0.240)	(0.110)	(0.946)	(0.546)
EndLocation	-0.488*	-2.351***	0.411***	0.084	-1.686***
	(0.271)	(0.237)	(0.135)	(0.503)	(0.387)
Penalty	-2.152***				-6.020***
	(0.269)				(1.318)
Bonus	-2.078***				-4.346***
	(0.273)				(1.357)
$Resource_t$*Penalty					0.028
					(0.014)
$Resource_t$*Bonus					0.005
					(0.015)
MidLocation*Penalty					1.571**
					(0.746)
MidLocation*Bonus					2.550***
					(0.766)
EndLocation*Penalty					2.530***
					(0.531)
EndLocation*Bonus					1.308**
					(0.523)
Constant	0.602	6.666	-2.041	-1.819	3.087
	(0.681)	(0.956)	(0.842)	(0.857)	(1.057)
Number of obs.	420	140	140	140	420

Note: Standard deviation is provided in parentheses. ***, ** and * denote the significance level of 1%, 5% and 10%, respectively.

The dummy variables for the penalty and bonus scenarios are statistically significant, indicating that the individual level of appropriation decreases by 2.15 units in the penalty scenario (and by 2.08 units in the bonus scenario) relative to the baseline case. We then estimate the parameters for the baseline, penalty and bonus scenarios separately. The next three columns of the table 4 display the results of this estimation.

The third column represents the estimates for the *baseline* scenario. The *p*-values of the estimated coefficients indicate that the individual's appropriation level in the previous period, the available stock in the current period, the farmer's education, his years of experience in agriculture, and his location in the irrigation system are all statistically significant. The estimates of this model suggest that the individual level of appropriation decreases by 0.11 units as the appropriation level in the previous period is increased in one unit. In contrast, it increases by 0.04 units for every additional unit of available stock. The individual appropriation also increases by 0.93 units if the subject has a bachelor's degree or higher. The years of experience in agriculture further increase the individual's level of appropriation, specifically, by 0.05 units for an additional year working in agriculture. Finally, subjects located in the middle and the end of the irrigation system appropriate on average 1.18 and 2.35 units less, respectively, than those at the beginning of the system.

The fourth column displays the results of the estimation for the *penalty* scenario.[32] The estimates of this model suggest that the individual appropriation increases by 0.37 units when the individual's appropriation level in the previous period increases by one additional unit. The subjects' choice is further increased by 0.06 units for each additional unit of available stock. Individual appropriation also increases by 0.04 units for each additional year of experience in agriculture, and subjects located at the middle and at the end of the irrigation system appropriate 0.68 and 0.41 more units, respectively, than those located at the beginning of the system.

The fifth column shows the results of the estimation for the *bonus* scenario. The *p*-values of the estimated coefficients indicate that the individual's own appropriation level in the previous period, the current available stock and the middle location are statistically significant. The results

[32] In this case, the individual appropriation level in the previous period, the available stock, years of experience in agriculture, the middle and end location along the irrigation system are all statistically significant.

also suggest that individual appropriation increases by 0.17 units as the individual's previous appropriation is increased in one unit. Furthermore, the subject's appropriation increases by 0.05 units for each additional unit of available stock. The estimate of this experimental variable is, hence, quite similar in signs and magnitude to the ones in the penalty scenario.

Finally, the last column of table 4 provides the estimation for the aggregated data of three scenarios with interaction variables. In particular, we include interaction variables between the available stock in the current period and the dummy variables for penalty and bonus scenarios. The estimation results indicate that these interaction variables are not statistically significant, thus suggesting that the coefficients for the available stock are not statistically different in magnitude between the three scenarios. In addition, we investigate how different policies affect subjects' appropriation decision relative to their location on the irrigation system. We, hence, include an interaction variable between the location and the penalty and bonus scenarios. The results indicate that, under the penalty and bonus policies, subjects located in the middle and end of the irrigation system appropriate more than those at the beginning.

The results of the econometric analysis support our hypothesis and suggest that participants choose to appropriate less in the penalty and bonus scenarios than in the baseline case. The estimates indicate that the knowledge of the stock is an important factor in their individual decisions in all scenarios. The magnitude of this factor is, however, not statistically different between the three scenarios. Furthermore, subjects' decisions in the previous period affect their appropriation level (both in the penalty and bonus scenarios), suggesting that previous choices persist in current appropriation decisions, even when the stock availability changes. In addition, the choice of policy has a different effect on subjects' decisions depending on their location on the irrigation system. The results indicate that subjects appropriate more if they are located at the middle and end of the irrigation system under the penalty and bonus rules.

6. Conclusion

Irrigation water is a constrained CPR resource in Uzbekistan that leads to an increasing competition over water allocation among farmers. Irrigation networks and policies, both created during the Soviet era, are putting more pressure on water reserves in this region. If such inefficient use of water resources continues, which focuses on agricultural output and ignores environmental impacts, the Uzbek's agricultural sector will be negatively affected. In this study we investigate farmers' water appropriation practices, and evaluate the benefits of two policies in terms of how they help to ameliorate the overuse of the resource.

Our experimental results indicate that, when protective policies are absent (baseline), farmers consistently overuse the resource without internalizing the negative externality that their overconsumption imposes on other farmers. Experiences during the Soviet era, when the use of water was very inefficient, lead farmers to this myopic behavior, which emerges in the form of higher levels of appropriation. We explain this overuse through two factors: the *optimistic effect* and the *fear effect*. In addition, our experimental results suggest that the penalty and bonus mechanisms reduce appropriation relative to the baseline case, and that the effectiveness of these policies depends on farmers' location along the irrigation system.

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