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Field experiments on irrigation dilemmas

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ABSTRACT

It is often assumed that irrigation systems require a central authority to solve coordination problems due to the asymmetry in position and influence between those located at the head-end of a system and those located at the tail-end. However, many examples of complex irrigation systems exist that are self-organized without central coordination. Field experiments on asymmetric commons dilemmas are performed with villagers in rural Colombia and Thailand. Our experiments show that there is a dynamic interaction between equality in the use of the common resource, and the level of the contributions to the creation of a common resource. Inequality in the distribution of benefits in one round triggers lower levels of group contributions, reducing efficiency and triggering even more inequality in contributions and distribution of the resource among players.

The upstream players act as "stationary bandits". They take more than an equal share of the common resource, but leave sufficient resources for the downstream players to stimulate them to continue their contributions to the public infrastructure.

After 10 rounds, players can vote on one of three allocation rules: equal quota, random and rotating access to appropriation of the resource. The rotating access is most often elected. The resource dynamics in the second part of the experiment depend on the rule elected. With the quota rule, the stationary bandit metaphor is less relevant since taking equal shares of the resource is enforced. With the rotation access rule, the players act strategically on the rotating position. They invest more when having the first access to the resource compared to less favorable access. And when they have first access they extract the main part of the common resource. The rotation rule led to a reduction of the performance of the groups. With the random access rule there is no such strategic investment behavior and participants remain investing equal and similar levels as in the first 10 rounds.

The experiments show that a necessary condition of irrigation systems to self-organize is the development of norms to allocate fair shares of the water in order to recruit sufficient labor to construct and maintain the physical infrastructure. The different allocation rules do not increase efficiency, but they did increase equality of the earnings.

1. Introduction

Collective action problems facing groups who jointly harvest from a common-pool resource such as a fishery, pasture, forest, or water system are difficult to solve. Each individual would be better off if everyone else cooperated and they could "free ride" and get benefits without any sacrifice. Selfish rational behavior leads to a tragedy of the commons (Hardin, 1968), but extensive field studies have provided many examples of long-lasting social–ecological systems where resource users have developed institutional arrangements without the external imposition of private or state ownership (Dietz et al., 2003).

The large amount of social dilemma experiments such as public good provision and trust games show that only a minority of participants in experiments behave as selfish rational actors (Camerer and Fehr, 2006). Most participants show other-regarding behavior, meaning that they value the returns received by others, like to avoid inequalities, value reputation and reciprocate cooperative behavior (Camerer and Fehr, 2006). This finding is consistent with the standard subject pool of undergraduate students in western

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societies, and holds with somewhat larger variability for non-traditional subject pools (Henrich et al., 2010). Furthermore, the level of conditional cooperation in experiments with resource users has been demonstrated to explain their behavior in the physical world (Rustagi et al., 2010).

In this paper we will continue to use the canonical selfish rational actor to explain the social dilemmas groups face. We do this to provide benchmarks of plausible outcomes (together with the also unrealistic social optimum outcome). Furthermore, small numbers of selfish rational actors affect cooperative groups and therefore robust institutional arrangements need to take this kind of behavior into account. Recent evolutionary models stress the importance of the interactions between selfish and prosocial agents and the possibility that strategies of one type invade the other (Richerson et al., 2002). Finally, there is no well-agreed upon alternative model that can be used to provide quantitative estimates of plausible behavior and explain observed behavior.

Differences of power among individuals need to be taken to account to understand cooperative behavior in complex societies. Such asymmetries might be the consequence of geography, social hierarchy, skills, knowledge, technologies and other attributes of the action arena. Olson (1993) studied the influence of asymmetries on collective action. For him, under anarchy, uncoordinated competitive theft by "roving bandits" destroys the incentive to invest and produce, leaving little for either the population or the bandits. Both would be better off if a bandit sets himself up as a dictator—a "stationary bandit" who monopolizes and rationalizes theft in the form of taxes. The main difference lies in the provision of security, which raises the incentive to produce. This explanatory model of political regimes has been recently applied to the case of the fishing industry, where fisheries move to new waters if an area is depleted, leading to a global collapse (Berkes et al., 2006).

Both common-pool resources and asymmetries of power are defining key characteristics of irrigation systems (Ostrom and Gardner, 1993; Aggarwal and Narayan, 2004). The asymmetry lies in differences among appropriators in their ability to access resources because of their location or the order in which they can benefit from the common-pool. It is often assumed that irrigation systems require a central authority to solve coordination problems (Hunt, 1988) due to the asymmetry in position and influence between those located at the head-end of a system and those located at the tail-end. Wittfogel (1957) argued that such central control was indispensable for the functioning of larger irrigation systems and hypothesized that some state-level societies have emerged as a necessary side-effect of solving problems associated with the use of large-scale irrigation. However, the control of centralized coordination is very difficult to maintain while many examples of complex irrigation systems exist that are self-organized without central coordination (Hunt, 1988; Lansing, 1991; Ostrom, 1992; Shivakoti et al., 2005).

Field research has thus shown that farmers are able, in many instances, to overcome the asymmetric collective action they face. Trying to understand why some farmers' groups are able to overcome this problem, however, is difficult if relying solely on field research given the large number of potential variables affecting behavior in dilemma settings. Experimental research can greatly complement knowledge obtained in the field due to control over the specific structural variables that participants in an experiment face (Harrison and List, 2004). This article presents the results of a set of behavioral experiments conducted with college students and with villagers in the field that address the problem of asymmetry in the governance of commons resources such as irrigation. We investigate the conditions that enable groups to overcome asymmetries of access and derive productive cooperative relationships.

The fundamental problem facing irrigation systems is how to solve two related collective action problems: (1) the provision of the physical and ecological infrastructure necessary to utilize the resource (water), and (2) the irrigation dilemma where the relative positions of "head-enders" and "tail-enders" generate a sequential access to the resource itself (water) (Ostrom and Gardner, 1993). If actors act as rational, self-interested agents, it is difficult to understand how irrigation infrastructure would ever be constructed and maintained by the farmers who obtain water from the system in comparison to a government irrigation bureaucracy. Even if the initial problem of providing the infrastructure were solved, water that is available to the head-enders may not necessarily be shared with the tail-enders, as long as the head-enders have a positive marginal return on the use of water. The vulnerability of irrigation system performance to the behavior of self-interested, rational actors leads to the question of why so many self-organized irrigation systems exist and persist for so long (Hunt, 1988; Lansing, 1991; Ostrom, 1992).

Earlier experimental studies on sequential decision making in commons dilemmas show that participants with first access take more and are expected to take more by downstream participants (Budescu and Au, 2002; Rapoport, 1997). In contrast to these earlier studies which only included the extraction phase of the commons dilemmas, this study also includes the provision problem.

We present results from field experiments in Colombia and Thailand. In both countries experiments were performed with villagers in rural environments and students in the respective capital cities. We included villages with different types of resource use to include a diversity of experiences with natural resource management, as well as students in urban environments. Our results indicate that the differences in experience do not have a significant effect for most decisions. In contrast, the expectations of trustworthiness of others in the community determine the initial level of cooperation. The share upstream participants take from the generated resource affect the adjustments of investment levels by downstream participants in subsequent rounds. There is a positive feedback between equity and efficiency that can result in greater or smaller levels of cooperation in the management of the asymmetric commons dilemma.

2. Experimental design

Our experiment was designed to be implemented in the field with participants who manage natural resources in their daily lives (see Appendix). In the irrigation game participants have positions A, B, C, D or E. A has the first choice to harvest water from the common resource. Then B has the next turn to harvest water from whatever amount was left by A, and so on. The location of the five players is randomly determined before the first round and remains fixed over the first set of ten rounds of the game. Participants receive an endowment ω of 10 tokens in each round. First each participant makes a decision x_i on how much to invest in a public fund that generates the infrastructure and therefore determines

Table 1
Water production as a function of units invested in the public infrastructure.

Total units invested by all 5 players	Water available
0–10	0
11–15	5
16–20	20
21–25	40
26–30	60
31–35	75
36–40	85
41–45	95
46–50	100

the amount of water available for the whole group to share. In Table 1, the water provision generated is defined as a function $f()$ of the total investments of the five participants.

Second, each player, in sequential turns from upstream to downstream players decides how much to extract from the water available to her, that is, the water produced minus the water extracted by those before her in the sequence. Each token kept (not invested) in the first stage has a monetary value for the player that is equal to the value of each unit of water extracted in the second stage. The fact that we randomly assign the positions in the experimental irrigation system provides a clean setup that would isolate other confound factors and allows us to measure the effect of the location asymmetry we want to study.

This experiment includes a first dilemma of upstream participants who need the contribution of downstream participants to maintain the structure of their common resource, which is crucial for the production of water in the game. However, the downstream participants can only obtain benefits from the resource if upstream participants avoid the temptation to deplete the common resource and leave little water for downstream players.

Under this asymmetric game, participants first experience a provision dilemma in the contributions stage, and then face a resource appropriation dilemma when they extract from the generated resource. The earnings of the participants are the result of provision – x_i – and extraction – y_i – decisions, and the resulting payoff z_i for player i is defined as

$$z_i = \omega - x_i + y_i, \tag{1}$$

where

$$\sum_{i=j+1}^{5} y_i \leqslant f\left(\sum_{i=1}^{5} x_i\right) - \sum_{i=1}^{j} y_i \quad \text{for } j = 0, 1, 2, 3, \text{ and } 4. \tag{2}$$

Due to the shape of the production function $f()$, no analytical formulation can be derived. However, we can calculate the Nash equilibrium and the social optimum numerically. If participants were rational self interested individuals nobody would invest in providing the infrastructure in the first round. Since the upstream participant is expected to collect the whole resource, downstream participants will not invest. For participant A there is no benefit to invest when others do not. If this is the reasoning of the participants in the last round of experiments we find via backward induction that the same happens for all earlier rounds. Thus, the Nash equilibrium for this game is that no one invests and all receive 10 tokens for group earnings of 50 tokens.

To define the social optimum solution we calculate the maximum amount of the infrastructure plus tokens not invested. There are multiple social optimum outcomes, all 104 units. For a 41 token investment, a resource of 95 tokens is generated in each round, and for a 46 token investment a resource of 100 tokens is generated in each round. The total earnings of the group in the social optimum amounts to 104 tokens. Hence the social optimum (assuming fully cooperating individuals) leads to more than double level of earnings compared to the outcome of selfish rational behavior and these outcomes provide the benchmarks of possible outcomes in the experiment.

3. Experimental setting

The pencil and paper-based experiments were held in six villages in Thailand and Colombia—three in each country. In each country one village would have a fishery as its dominant resource use fishery, one a forest and one an irrigation system (see Table 2). In Thailand, the experiments were performed in three separate locations in the Petchaburi watershed, which runs toward the west coast of Thailand Gulf. One of the locations is in the coastal area, and the other two are inland. The Colombian experiments were conducted in three different rural sites. The fishery community is represented by a village on Barú Island, (a rural area of Cartagena city, on the Caribbean coast). The irrigation community is located in the Fuquene lake basin area, located in the Andean region of Cundinamarca and Boyacá. And the forestry community is located in Salahonda, on the Pacific coast tropical forest area. For each of these locations permission to perform experiments was given by the head of the village. The experiments were held during the first 6 months of 2007. Typically 4 days of experiments were followed by in-depth interviews with a sample of relevant stakeholders of the village.

The participants were recruited via word of mouth and flyers hung throughout the village inviting participants 18 years and older to participate. Special effort was made to recruit adults from households engaged in the resource extraction of that village. Only one member of a family was allowed during the same session. At the end of the series of experiments a handful of people were identified for in-depth interviews. Those individuals, who were interviewed were selected from among the participants and are biased toward resource-specific users. At the end of the week, a session was organized to discuss the experiments.

Each of the irrigation games was conducted with 4 groups of 5 people. As a result 20 persons participated in each of the six villages, leading to a total of 120 individuals. In 2008 the experiments were replicated by using the same protocol with university students in Bogota and Bangkok, with 20 students (4 sessions) in each city. In both the villages and at the campuses the experiment was explained in the context of irrigation.

The average age of the villager participants was 37 years (Std. Dev. 13.8), and 39% of them were female. About two thirds of them reported living in their village their entire life. Among the student participants the average age was 20 years and 62% of them were female. The education level of the villagers varied. Five percent of them had no formal education, and about 28% of them had some or complete primary education. Fifty-three percent of the players had secondary education and only 15% received technical or university training.

In the experiment, the participants knew who else is participating, but they do not know the individual decisions of the other individuals during each of the 20 rounds that the experiment lasted for each group. Only the aggregate outcomes of the decisions are presented to the group. They are not allowed to communicate with others during the experiment. Assistants were made available during the experiments for those participants who had difficulty with reading and/or arithmetic.

After instructions and practice rounds, the participants play for 10 rounds under a baseline treatment. After the 10th round, three different rules are presented for participants to choose from.

Rule 1 (random order rule): Each round, after participants have contributed to the maintenance of the irrigation system, and the amount of water available is announced, the order in which one can take water for irrigation will be assigned randomly to participants.

Rule 2 (rotation rule): There will be a fixed rotation in which one can collect water. This order is a 5 round rotation system: ABCDE, BCDEA, CDEAB, etc. After 10 rounds each player will have had two chances to be first in the sequence, two chances to be second, and so on.

Rule 3 (quota rule): Each of the participants has a right to 20% of the water of the irrigation system. This amount is calculated after the available water is announced. The order to extract water remains the same for all the rounds: ABCDE. A die is thrown in each round. When 6 is thrown, an inspector arrives and will check the water extraction. The participant pays back

Table 2
Sample descriptive statistics.

	Colombia				Thailand			
	Fishery village	Forestry village	Irrigation village	Bogota	Fishery village	Forestry village	Irrigation village	Bangkok
Investment[a]	4.37	3.88	3.97	3.90	5.22	6.25	6.51	5.34
Earnings[b]	12.88	11.36	11.58	12.86	14.50	16.38	17.01	14.83
Age	29.5	35.2	32.7	20.2	46.1	42.3	35.5	19.1
Male	100%	95%	45%	55%	45%	35%	45%	20%
Married	60%	65%	70%	0%	80%	80%	85%	0%
Education[c]	2.6	1.8	2.3	4.2	3.2	3.5	3.4	6
Trust[d]	0.68	0.51	0.41	0.56	0.73	0.63	0.65	0.53

[a] The average investment per round (between 0 and 10) of individuals into the provision of water.
[b] The average earnings per round per individual (between 0 and 30).
[c] What is the highest grade you have completed in school? 0 – None; 1 – some primary school; 3 – primary school; 4 – secondary school; 5 – technical; 6 – University; 7 – post-university.
[d] The trust index is calculated by aggregating six survey questions relating to trust and the community, using a likert scale (whether in general the person agrees or disagrees with certain statements, assigning 1 point for Strongly agree, 2 points for agree, 3 points for disagree, 4 points for Strongly disagree, using this formula. (B + C − A − D − E − F + 14)/18. The statements were the following: (A) most people in this village are basically honest and can be trusted. (B) People in this village are mostly interested in their own well-being. (C) In this village one has to be alert, or someone will take advantage of you. (D) If I have a problem there is always someone in this village to help you. (E) Most people in this village are willing to help if you need it. (F) If you lose a pig or chicken someone in the village would help look for it or would return it to you.

the extra amount taken, and an extra amount of 6 units if more than their allotment—20% of the resource—is taken.

Note that the Nash equilibria will be the same for all three types of rules, namely that nobody will have material incentives to invest in the public infrastructure. Differences in rule preference may reveal different expectations, preferences and experiences. Each participant can vote for their preferred rules, which will be implemented in a subsequent series of rounds if three or more players vote for it. If two rules get two votes, an additional round of votes between those two candidates is used to determine the final chosen rule. The three rules are effectively a lottery in access to water, a rotation in access to water or a maximum legal water quota. All rules are aimed at solving the resource dilemma by regulating the over extraction of the resource in the appropriation stage, and thus achieving the goal that each of the five players has an equal share of the resource over the duration of the game.

Ten rounds are played with the new rule implemented. The first round after the election has the same starting situation as round 1 of the experiment. Before the participants receive their payments, they fill out a general survey on their demographics and resource use within the village. The duration of an experimental session was about 3 h and the typical earnings of the participants was worth between one and 2 days of labor.

4. Results

Fig. 1 shows the average level of contributions to the public fund by all villager and student groups in each round, and for the two different stages (before and after the rules were introduced). Fig. 1 shows that there is a slight but significant decrease in social efficiency after the rule change. The average earnings per person for the second stage decreases from an average of 14.40 units per round per player to 13.32 units (Wilcoxon Matched-Pairs Signed-Ranks Test, 32 observations, p-value = 0.008) for the entire sample. The Thai participants create more public infrastructure than the Colombian participants (Fig. 2) (Mann–Whitney two-tailed test, $n_1 = 16$, $n_2 = 16$, p-value = 0.001 for the first 10 rounds, and p-value = 0.008 for the second 10 rounds). The student groups create less public infrastructure than the rural villagers but not at a significant level (Fig. 3) (Mann–Whitney two-tailed test, $n_1 = 24$, $n_2 = 8$, p-value = 0.334 for the first 10 rounds and p-value = 0.404 for the second 10 rounds). There is also no significant difference between irrigation villages and other rural villages in the amount of infrastructure generated (Mann–Whitney two-tailed test, $n_1 = 160$, $n_2 = 80$, p-value = 0.881 for the first 10 rounds, and p-value = 0.568 for the second 10 rounds).

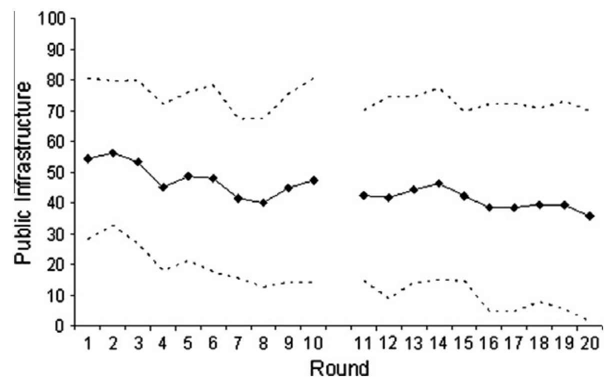

Fig. 1. The average level of the generated public infrastructure (where the dotted line is average ±standard deviation) using data of all 160 persons.

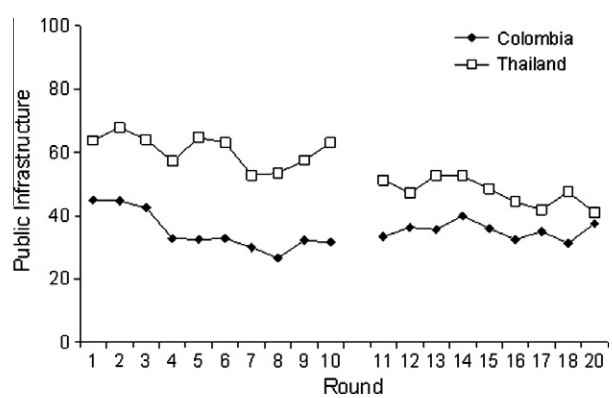

Fig. 2. The average level of the generated public infrastructure for Colombian and Thai groups.

The average earnings per group in the first 10 rounds are depicted in Fig. 4, which confirms the trend in investments in the public infrastructure. Thai groups earn more than Colombian groups irrespective of whether they are irrigators, villagers or students.

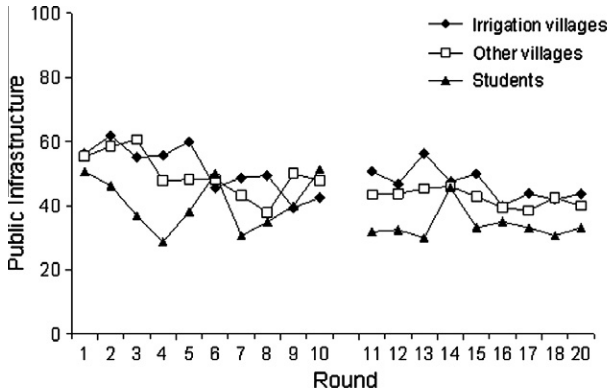

Fig. 3. The average level of the generated public infrastructure for irrigation village groups, groups from other villages, and student groups.

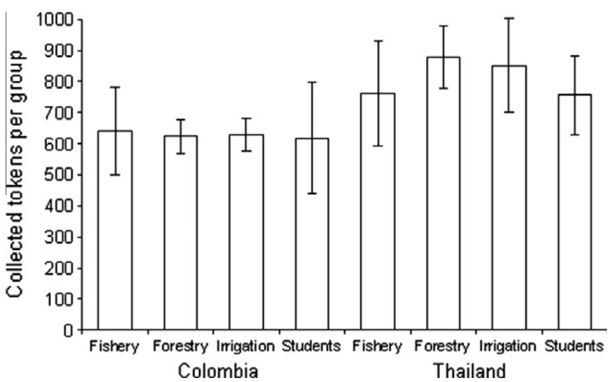

Fig. 4. Average level of collected tokens for 10 rounds for each village. The error bars indicate the standard deviation of the four groups within each village.

In Fig. 5, we report the average contributions to the infrastructure in each of the locations in the watershed and compare the first stage (rounds 1–10) to the second stage (rounds 11–20). In the second stage we distinguish the data from the actual positions (i.e., individuals change positions during a rotation rule), and the original position they started with in the first 10 rounds). There is no difference in the level of contributions to the infrastructure among the different locations if we use the original positions (Mann–Whitney tests), but for the actual positions we find upstream participants invest more as we discuss below. Note that in Table 3, discussed below, there is a position effect if we use the actual position and control for social–economic and behavioral factors.

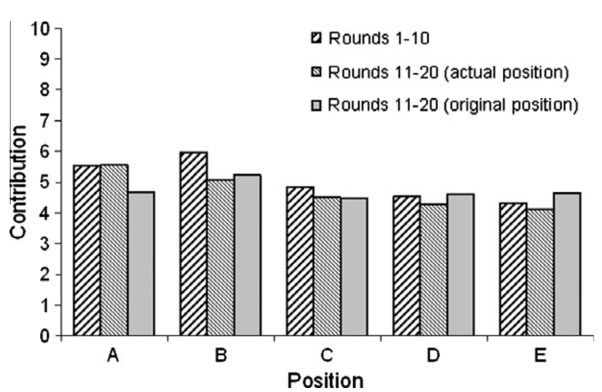

Fig. 5. Average investment in the public infrastructure by location in the watershed (Water Irrigation Game) averaged over 10 rounds using data of all 160 persons.

There is a significant inequality of the extraction levels across participants upstream, A and B, and the participants downstream, D and E (Fig. 6) (using Mann–Whitney tests). In fact the downstream participant on location E contributes on average more to the infrastructure than he or she receives back from the common resource. Hence the participant in position E gives up some earnings to the upstream participants. In the second stage a redistributive transfer occurs that improves the earnings of players D and E (original positions), although the inequality remains when using the order in which participants take turns. The losses in total efficiency are compensated by the gains in a more equal distribution. Below we discuss the second stage of the experiment in more detail. We especially investigate the effects of different rules elected on the relative earnings of participants.

4.1. Individual level analysis

What determines the investment levels of the participants? In particular, why do downstream participants keep on investing in the public infrastructure if they receive unequal amounts from the common resource?

Since we have data at the country, village, group and individual level, where error rates of higher levels might be influenced by lower level decisions we use a hierarchical linear model that allows us to control for variability of individuals within a group as well as group specific error rates. Such estimator will allow us to explore the simultaneous effect of experimental factors, individual characteristics as well as contextual variables, which ended up explaining part of the variation of the behavior in the experiment. We used Stata 10.0 and the command xtmixed for the estimation procedure (Rabe-Hesketh and Skrondal, 2008).

For the contribution level in the first round we find that persons with a higher level of trust in others in the community (measured in the survey) contribute more (Table 3). Other factors related to natural resource management experience, such as being a member of an irrigator community, being a resource user versus a housekeeper or merchant, for example, or being a student versus a villager, had no significant effect on the level of contributions in the first round. Furthermore, we do not find a significant effect based on the position of the participant. The results suggest that trust of others in the community is the primary factor determining the initial contribution levels in the community activity.

The contributions in subsequent rounds are affected by a number of factors. First, we found that participants from Thailand contribute more than participants from Colombia. We also found that villagers who are actual resource users invest more than other villagers. The level of investments was moreover affected by both position and return on investment in the previous round. Upstream participants invest more, but not those upstream participants who derive a high return on investment, meaning they take much more in the extraction phase than they invested. This leads to similar levels of average investment among the positions (Fig. 5). When access to the common resource is randomly assigned, the level of investment is higher since there is no strategic advantage of the position.

To analyze the effect of participant attributes on the extraction decisions relative to the amount available to participants, we analyzed the relative extraction decisions for each position (Table 4). Since the common resource is more likely to be depleted when a downstream person has to make a decision, we have fewer observations for downstream participants. In general we find that student participants derive a higher share from resources available to them compared to the villagers. Furthermore, we find evidence for conditional cooperation. When higher levels of the common resource are generated (Initial Resource, Table 4) a relative lower share is collected, rewarding the participants downstream of those

Table 3
Regression results for four analyses for *individual level* data explaining the contributions in round 1, rounds 2–10, rounds 12–20, and rounds 2–20. Between brackets are the standard deviations. We used a multi-level analysis, and the significance metric is reported by χ^2.

	Round 1	Rounds 2–10	Rounds 12–20	Rounds 2–20
Constant	**4.000***** **(1.074)**	**2.561***** **(0.468)**	**4.333***** **(0.724)**	**3.240***** **(0.383)**
Country (Thailand = 1)	0.773 (0.572)	**0.777***** **(0.247)**	**1.336***** **(0.364)**	**1.052***** **(0.278)**
Irrigation village (yes = 1)	0.205 (0.621)	0.138 (0.290)	0.608 (0.461)	0.313 (0.336)
Student (yes = 1)	−0.469 (0.622)	**−0.588**** **(0.299)**	0.227 (0.458)	−0.263 (0.339)
Position	−0.170 (0.136)	**−0.259***** **(0.056)**	**−0.493***** **(0.052)**	**−0.376***** **(0.038)**
Gender (woman = 1)	0.247 (0.460)	0.100 (0.157)	**−0.344**** **(0.158)**	−0.120 (0.114)
Resource user	−0.172 0.507	0.286 (0.187)	**0.318*** **(0.190)**	**0.316**** **(0.137)**
Trust	**2.873**** **(1.387)**	0.384 (0.511)	−0.567 (0.532)	0.019 (0.383)
Round		−0.021 (0.024)	−0.037 (0.024)	**−0.031*** **(0.017)**
Investment ($t-1$)		**0.529***** **(0.026)**	**0.444***** **(0.026)**	**0.491***** **(0.018)**
Return on investment ($t-1$)		**−0.083**** **(0.042)**	**−0.140***** **(0.044)**	**−0.098***** **(0.029)**
Return on investment ($t-1$) * position		0.015 (0.017)	**0.027**** **(0.012)**	**0.016*** **(0.009)**
Rule 1			1.168 (0.741)	**0.949***** **(0.317)**
Rule 2			−0.353 (0.441)	0.011 (0.201)
Rule 3				0.330 (0.249)
N	160	1336	1330	2666
−Log likelihood	376.373	3007.537	2985.894	5997.562
χ^2	2.93 (p = 0.403)	24.37 (p = 0.000)	74.32 (p = 0.000)	120.39 (p = 0.000)

*** $P < 0.01$.
** $P < 0.05$.
* $P < 0.1$.

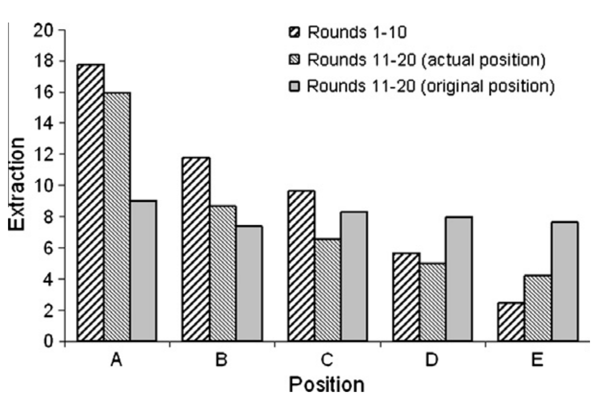

Fig. 6. Average extraction from the water resource by location in the watershed (Water Irrigation Game) averaged over 10 rounds using data of all 160 persons.

who take a small share. When a higher share of the resource remains available for the participants downstream (Share resource left, Table 4), those participants are also less greedy the participants downstream to them. Similarly, if upstream participants take a relative large share, the participants downstream are eager to follow this behavior.

Over the rounds, participants take higher shares if they have the chance. For the upstream participants we also find that higher levels of trust correlate with higher shares taken from the common resource. This may mean that participants trust others will not retaliate if they take a bit more than an equal share.

In sum, the individual level analysis shows that the decisions made by participants in the first round are related to trust in participants of the community. In subsequent rounds, the position of participants affects the contribution and extraction of the resources. Participants in position A and B particularly have a major influence on the allocation of the resource. This analysis suggests that actions made in previous rounds do affect the individual level decisions. We show that this also holds at the group level.

4.2. Group level analysis

We explore the interaction between group contributions to the public fund (from 0 to 50 units) and the distribution of contributions and of benefits (collection of units) using the Gini coefficient (ranging from 0 to 1) for the five players in any particular round. In the first regression (Table 5) we see that none of the factors can explain the level of contributions. Other factors related to natural resource management experience, such as being part of an irrigator

Table 4
Regression results for analyses for *individual level* data for the relative share of the available resource extracted by each position for rounds 1–20. Between brackets are the standard deviations. We used a multi-level analysis, and the significance metric is reported by χ^2.

	Relative share				
	A	B	C	D	E
Constant	**0.162*** **(0.091)**	**0.527***** **(0.084)**	**0.693***** **(0.102)**	**0.878***** **(0.098)**	**0.807*** **(0.109)**
Country (Thailand = 1)	−0.107 (0.074)	**−0.150***** **(0.056)**	−0.006 (0.090)	−0.058 (0.066)	**0.175***** **(0.060)**
Irrigation village (yes = 1)	**0.151*** **(0.090)**	−0.091 (0.069)	0.043 (0.110)	**−0.217***** **(0.082)**	0.065 (0.071)
Student (yes = 1)	**0.291***** **(0.091)**	**0.195***** **(0.068)**	**0.209**** **(0.107)**	0.051 (0.081)	0.101 (0.071)
Gender (woman = 1)	**−0.074***** **(0.025)**	**0.060**** **(0.027)**	**−0.082***** **(0.030)**	−0.023 (0.027)	**−0.079***** **(0.031)**
Resource user	−0.009 (0.028)	0.041 (0.033)	0.034 (0.031)	0.036 (0.033)	0.029 (0.042)
Trust	**0.374***** **(0.094)**	**0.232**** **(0.101)**	**0.311***** **(0.102)**	−0.140 (0.108)	0.091 (0.132)
Round	**0.012***** **(0.003)**	**0.006*** **(0.003)**	0.002 (0.003)	0.002 (0.003)	0.000 (0.003)
Relative contribution	**0.335***** **(0.075)**	0.129 (0.086)	0.044 (0.087)	**0.219*** **(0.108)**	0.104 (0.117)
Initial resource	**−0.001***** **(0.0004)**	**−0.001**** **(0.0005)**	**−0.002***** **(0.0004)**	**−0.001**** **(0.0005)**	**−0.001*** **(0.0006)**
Share resource left		**−0.290***** **(0.047)**	**−0.514***** **(0.0056)**	**−0.358***** **(0.075)**	**−0.663***** **(0.138)**
Rule 1	0.015 (0.054)	**−0.212***** **(0.056)**	−0.007 (0.050)	**−0.179***** **(−0.057)**	0.016 (0.062)
Rule 2	−0.022 (0.032)	**0.067*** **(0.035)**	−0.019 (0.031)	0.011 (0.039)	0.005 (0.043)
Rule 3	−0.125 (0.043)	**−0.075*** **(0.045)**	**−0.113***** **(0.042)**	−0.014 (0.047)	**0.148***** **(0.052)**
N	595	535	480	386	310
−Log likelihood	117.753	103.941	145.38	115.202	98.963
χ^2	351.26 (*p*-value = 0.000)	97.25 (*p*-value = 0.000)	251.69 (*p*-value = 0.000)	66.16 (*p*-value = 0.000)	97.66 (*p*-value = 0.000)

*** $P < 0.01$.
** $P < 0.05$.
* $P < 0.1$.

community, or being a student group or not, had no significant effect on the level on contributions in the first round.

In the second column we look at the contribution levels in subsequent rounds until round 10. We see that trust has no significant effect, but inequality of contributions do. In subsequent rounds (12–20), as reported in the third column, we observe the robust and substantial effect that the inequality in contributions and extractions of the previous round has on group contributions. Moreover, we see that inequality is affected by the level of group contributions (Table 6). Lower group contributions correlate with higher levels of inequality in the level of contributions and extractions. Table 6 also shows that inequality is increasing over the rounds before rules are implemented. Furthermore, the rotation rule leads to more inequality in the level of contributions. We discuss this in more detail below.

The logic behind the effect of inequality on contributions is simple: players can infer from their respective locations and choices in terms of contributions and extraction how unequal the process was, because they are told of the group contribution in each round and they are also told of the remaining water left to them by the players upstream. The data given to participants help them to figure out the equality of the contributions and of the outcome at the group level. Levels of inequality seem to trigger the reaction in the next round in terms of contributions. In a nutshell, inequality in the distribution of benefits in one round triggers lower levels of group contributions, reducing efficiency and triggering even more inequality in contributions and distribution of the resource among players. This effect is more profound after the rules are implemented since following the rules would lead to more equal distribution of the generated water resources. The last column shows the effect for round 2 through 20. The rule 1 leads to a significant increase in the group contributions. The other 2 rules have no significant effect. Note that for the third column in Table 5, rule 3 was excluded due to collinearity.

Out of 32 groups, 22 elected the rotation rule for the second part of the experiment, while 3 groups elected the random order and 7 groups the personal quota rule. We do not find a difference in the voting behavior of participants between villagers and students (Mann–Whitney *p*-value = 0.273). The elected rules lead to lower levels of public infrastructure and earnings in rounds 11–20 (*p*-values < 0.01 for the Mann–Whitney tests).

While the elected rules lead to a drop in performance this is mainly caused by the effects of the rotation rule (Fig. 7). To understand what is causing the negative outcomes for the rotation rule we look at the effect of decisions made by participant A on the group contributions in the next round. During the first 10 rounds of the experiment, the group contributions average 22.55 if the participant A took 20% or less of the common resource in the previous rounds, and 17.71 if this share was 50% or more (Mann–Whitney test ($U = 5391.5$, $n_1 = 106$; $n_2 = 76$; *p*-value < 0.001)).

Table 5
Regression results for analyses for *group-level* data of group investments in rounds 1–20. We used a multi-level logistic regression and the significance metric is reported by χ^2.

	Round 1	Rounds 2–10	Rounds 12–20	Rounds 2–20
Constant	**22.849*****	**19.799*****	**25.422*****	**22.853*****
	(7.925)	**(5.364)**	**(5.785)**	**(4.385)**
Country (Thailand = 1)	1.892	**4.717****	**5.881*****	**4.906*****
	(3.397)	**(1.941)**	**(2.208)**	**(1.678)**
Irrigation village (yes = 1)	−1.421	−0.068	0.962	0.040
	(4.299)	(2.426)	(2.735)	(2.096)
Student (yes = 1)	−4.865	−2.517	−0.538	−1.446
	(4.806)	(2.729)	(3.063)	(2.344)
Fraction of women	4.804	2.449	0.641	1.561
	(5.761)	(3.256)	(3.67)	(2.803)
Fraction of resource users	2.671	0.049	−4.183	−1.141
	(5.303)	(2.998)	(3.652)	(2.606)
Trust	7.151	0.054	−1.845	−1.106
	(8.239)	(4.668)	(5.281)	(4.034)
Gini contributions ($t-1$)		**−8.005***	**−10.842*****	**−9.859*****
		(4.501)	**(3.888)**	**(2.996)**
Gini collection ($t-1$)		−3.392	**−9.933*****	**−8.854*****
		(2.859)	**(2.173)**	**(1.584)**
Group contribution ($t-1$)		**0.259*****	**0.160****	**0.284*****
		(0.072)	**(0.071)**	**(0.051)**
Round		−0.070	−0.073	−0.018
		(0.124)	(0.104)	(0.082)
Rule 1			**10.455*****	**3.275****
			(3.636)	**(1.509)**
Rule 2			2.222	−0.576
			(2.119)	(0.939)
Rule 3				−1.451
				(1.242)
N	32	275	266	541
−Log Likelihood	107.257	854.013	795.652	1644.735
χ^2	0 (p = 1.000)	13.41 (p = 0.004)	18.25 (p = 0.000)	50.51 (p = 0.000)

*** $P < 0.01$.
** $P < 0.05$.
* $P < 0.1$.

This suggests retaliation for the unequal share taken by participant A. When we have different rules in the second part of the experiment, the quota rule shows a strong retaliation effect on high shares taken by the participant in location A. If this person takes 20% or less in the next round the group will invest 26.9 tokens, but if this person takes 50% or more, the group will invest 14.8 tokens (Mann–Whitney test$U$ = 850.5, n_1 = 98, n_2 = 10, p-value < 0.001). For the other rules, the effect is not significant for a p-value of 0.01.

Moreover we see that the contributions and extractions at the round level are increasingly unequal for the rotation rule, but increasingly equal for the other two rules (see Figs. 8–10). The increasing inequality in the rotation rule leads to lower contributions in subsequent rounds. Fig. 11 shows the average contributions and extractions for participants during the rotation rule using the rotation positions. Like Fig. 6 there is a substantial inequality in extraction levels. How much a person collects depends now on the rotation position of that person in that round. Unlike the first 10 rounds (Fig. 5) the contributions are also unequally distributed. Participants who have the first turn invest significantly more than participants in downstream positions, using Mann–Whitney tests.

It is very plausible that negative reciprocity triggers such patterns of behavior and outcomes, causing a decrease in efficiency for most of the groups that had chosen this rule. Participants know when it is their turn to be upstream and take a large share. When they are not in the first position, they have some information of how much upstream players are taking. Players downstream notice that the first player extracts a larger amount and therefore act according to a reciprocal strategy of tit-for-tat, producing an overall underperformance of the institution. This explanation is also consistent with the fact that players who will extract first are investing more in the contributions stage. Their investment will increase the available water for which they have more secure property rights. For the random order rule such strategic behavior is not possible, while the quota rule reduces the level of unequal amounts taken by the participants.

Nevertheless, even in the rotation rule we still observe that players also invest tokens when they are not upstream. There are at least two possible explanations. Players might be interested in investing because of other-regarding preferences which trigger a willingness to contribute to a public good. Mechanisms such as "warm glow" or a sense of guilt or duty toward the experimenter can also be emotional motivations for contributing at least some tokens to the maintenance of the irrigation system. This could be enhanced by the framing of the game. Reference to water may trigger a sense of duty to contribute for all community members. Another explanation is the production technology. As one can see in Table 2, the production function shows a first stage of increasing returns from 0 to 21–25 tokens. In other words, every additional token invested within this range increases the proportion of water produced and therefore there are individual and group incentives to move closer to such an inflection point. After that stage the marginal returns on investment are still positive but decreasing.

A remarkable finding in our analysis is the seemingly similar behavior of villagers and students. However, we observed an interesting difference between villager and student participants,

Table 6
Regression results for analyses for *group-level* data of inequality of contributions and collections from the common resources in rounds 2–10 and rounds 12–20. We used a multi-level analysis and the significance metric is reported by χ^2.

	Gini collection		Gini contribution	
	Rounds 2–10	Rounds 12–20	Rounds 12–20	Rounds 2–20
Constant	**0.457***** **(0.123)**	**0.532***** **(0.188)**	**0.452***** **(0.077)**	**0.302***** **(0.066)**
Country (Thailand = 1)	0.003 (0.046)	0.061 (0.059)	−0.016 (0.031)	**−0.047**** **(0.023)**
Irrigation village (yes = 1)	−0.029 (0.058)	−0.058 (0.073)	−0.028 (0.038)	0.010 (0.027)
Student (yes = 1)	−0.065 (0.065)	−0.096 (0.081)	0.037 (0.043)	0.044 (0.030)
Fraction of women	−0.005 (0.078)	−0.002 (0.096)	0.057 (0.051)	**0.073**** **(0.037)**
Fraction of resource users	−0.057 (0.072)	0.014 (0.099)	0.006 (0.047)	−0.0002 (0.037)
Trust	−0.093 (0.112)	−0.097 (0.144)	−0.063 (0.074)	0.033 (0.053)
Gini contributions ($t-1$)			0.035 (0.052)	**0.203***** **(0.056)**
Gini contributions	0.065 (0.095)	0.068 (0.114)		
Gini collection ($t-1$)	**0.324***** **(0.057)**	**0.181***** **(0.064)**	**0.070*** **(0.039)**	**0.110***** **(0.034)**
Group contribution	**−0.004***** **(0.001)**	**−0.010***** **(0.002)**	**−0.009***** **(0.001)**	**−0.007***** **(0.001)**
Round	**0.007***** **(0.002)**	0.002 (0.003)	**0.004**** **(0.002)**	0.002 (0.002)
Rule 1				0.020 (0.037)
Rule 2		**0.148*** **(0.082)**		−0.013 (0.022)
Rule 3		−0.017 (0.098)		
N	266	252	275	266
−Log likelihood	228.277	148.322	334.779	296.675
χ^2	8.93 (p = 0.030)	19.47 (p = 0.000)	45.1 (p = 0.000)	5.58 (p = 0.134)

*** $P < 0.01$.
** $P < 0.05$.
* $P < 0.1$.

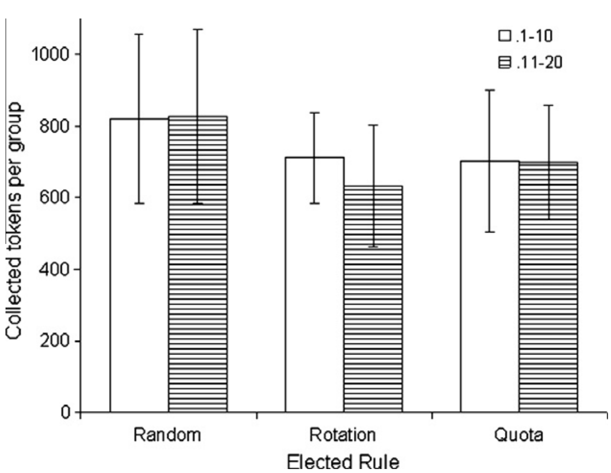

Fig. 7. Average level of collected tokens for 10 rounds before and after rule election for each rule. The error bars indicate the standard deviation of the groups who elected the particular rule.

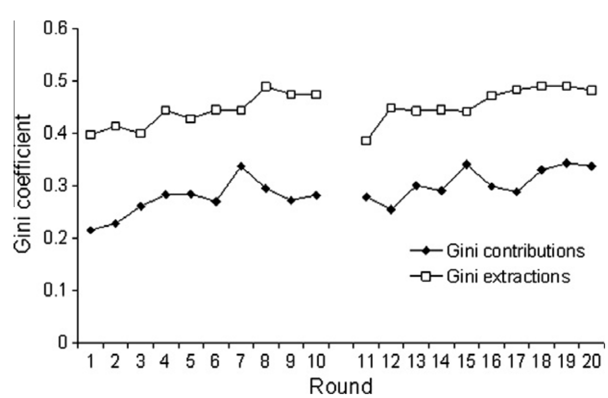

Fig. 8. Gini coefficients for contributions and extractions within groups at the round level. The Gini coefficients are averaged over all groups.

namely in the choices that players in position E make. In the first 10 rounds villagers in position E take 73% of the tokens available to them. They leave 27% of the available tokens untouched, even though they receive on average less than the amount of tokens invested. The majority of villagers who had the opportunity have shown this behavior. This is not the case with student participants in position E who collected 100% of the tokens available. Our post-

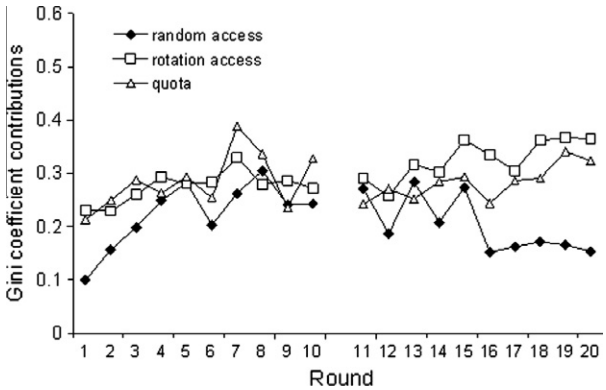

Fig. 9. Average of Gini coefficients for contributing to the infrastructure where the groups are split up into the rule they have elected for rounds 11–20.

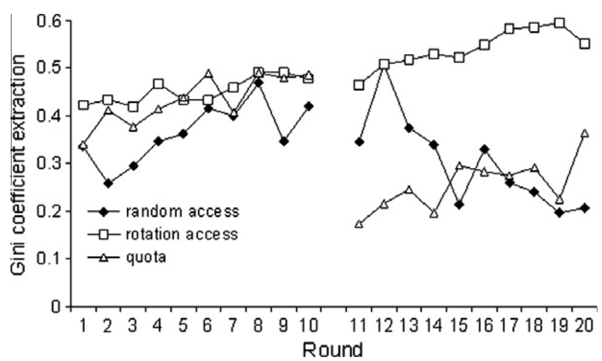

Fig. 10. Average of Gini coefficients for extraction from the common resource where the groups are split up into the rule they have elected for round 11–20.

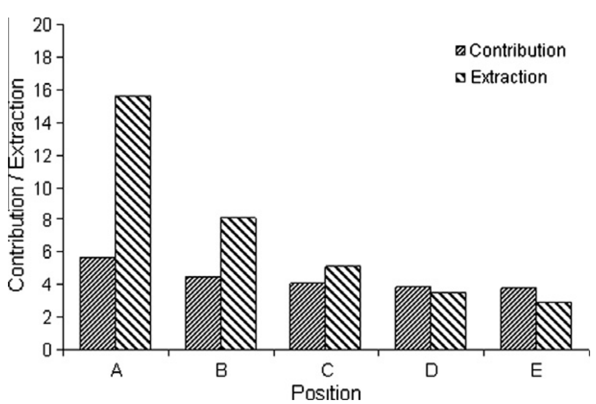

Fig. 11. Average investment in the public infrastructure extraction from the water resource by rotation turn averaged over 10 rounds (11–20) for all 110 persons participating in groups with the rotation rule.

game interviews with a selected number of participants who represented key resource users gave us answers to this problem. In several occasions, when asked about why on average players in the E position left water in the irrigation system, they responded that one should not take all the remaining water as there are always people downstream, or that the trees and birds may need those last drops of water. This may be used as a response that attempts to appeal to experimenters, or an artifact of the mild framing of the experiment, but the fact is that such units not extracted by player E is like money left on the table. Regardless of the explanation, the example of villagers who decided to forego such additional income in exchange for the symbolic value of not exhausting the resource, reinforces too the added value of conducting experiments in the field where the context might be richer than in college laboratories (Henrich et al., 2010).

5. Discussion

Our analyses demonstrate a synergic process between efficiency and equity. Our regression analysis at the group level shows that a more inequitable extraction of the resource by the group members in one round leads to lower levels of contributions to the provision of the public infrastructure in the next round and to a more unequal allocation of the resource. Likewise, an unequal distribution of the resource in one round erodes group contributions in the next round and exacerbates the inequality in the final distribution of the benefits from the irrigation system.

Physical location in the system, however, does play a crucial role. Upstream players are capturing a substantial share of the benefits of cooperation from the group. They act like "stationary bandits" who capture more than an equal share of the revenue (Olson, 2000). In Olson's model, stationary bandits, as contrasted with "roving bandits," leave some resources for the other players so that the others continue to contribute to the collective benefit even though the stationary bandit is able to take a larger share of the benefits. That is exactly what we observe during the ten first rounds. We also observe that, consistent with Olson's model, the stationary bandit's interest is to try to identify the revenue-maximizing tax rate (which here is the maximum extraction that does not discourage the other players to invest during the next rounds). This is the case with our results: if player A extracts more than 50% instead of 20% or lower, the contributions of other players are significantly lower. We also observe that when allocation rules are applied the results are different. With the quota rule, the stationary bandit metaphor is less relevant since taking equal shares of the resource is enforced. With rotation and random assignment, the situation is a quasi-stationary bandit. Players who can extract the maximum of water will do so because they know that this is a temporary situation. The difference with Olson's roving bandit is the fact that all players are potential roving bandits who will benefit from the position at some stage. In the random order rule the participants cannot act strategically on this, but with the rotation rule, participants in the downstream position invest a minimum in public infrastructure.

Unequal distribution of extraction exacerbates the dynamic just mentioned by eroding the levels of contributions by the group. The rules tested in the experiments were aimed mainly at improving the equality of the allocation of the final outcomes. They did achieve such an objective over the course of 10 rounds. Since participants respond to the equality observed at each round, however, the decline of investment levels continues, especially for the rotation rule.

These results provide support for the importance of conditional cooperation for the maintenance of common resources. Individuals adjust cooperative behavior when observing unequal outcomes. Experiencing a disadvantageous inequality creates a sense of envy because of other peers deriving more benefits than the individual of reference. Experimental studies using the Ultimatum game and the third-party punishment game confirm that individuals are willing to forego material personal income with the purpose of inducing more equal outcomes both when they are directly involved or as third-party observers respectively (Cameron, 1999; Güth et al., 1982).

The observation that participants with higher trust in other village members contribute more to the public infrastructure is also supportive of the importance of social capital for natural resource governance (Pretty, 2003). Case study analysis of irrigation systems has shown that irrigation systems where local water-user groups develop their own rules have a higher level of efficiency and equity of water use (Joshi et al., 2000; Lam, 1998; Pretty and Ward, 2001).

Despite asymmetry in access to common resources, groups can derive high levels of efficiency if individuals with more access to the commons refuse the temptation to take very unequal shares. The experiments show that a necessary condition of irrigation systems to self-organize is the development of norms to allocate fair shares of the water in order to recruit sufficient labor to construct and maintain the physical infrastructure. Sufficient levels of trust in other members of the community overrides power differences among the resource users.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.agsy.2012.03.004.

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