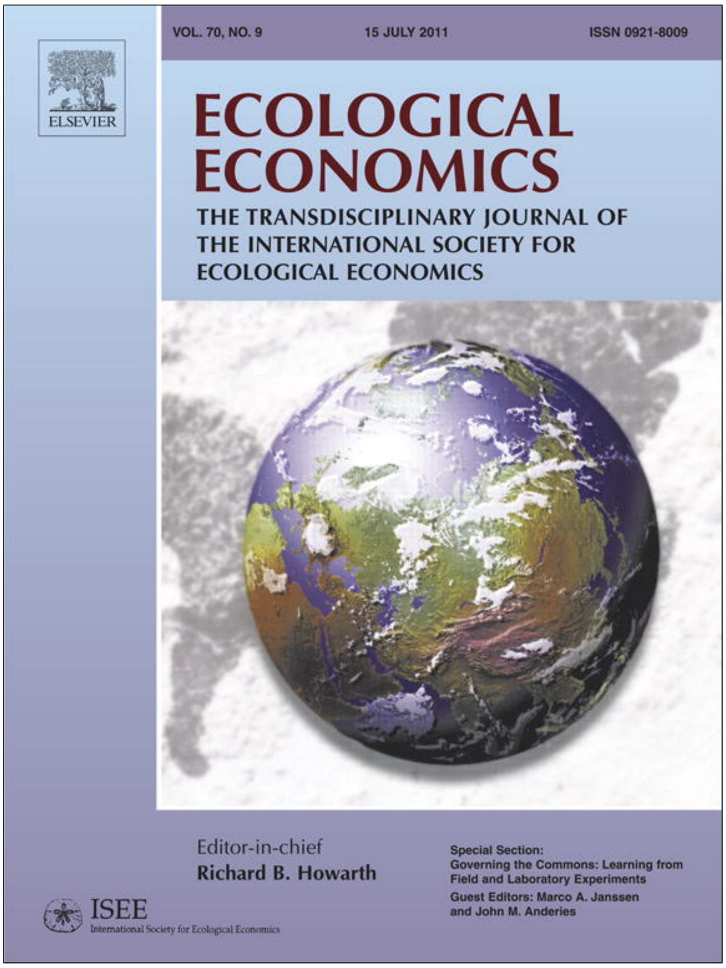

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Head-enders as stationary bandits in asymmetric commons: Comparing irrigation experiments in the laboratory and the field

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ABSTRACT

The emergence of large-scale irrigation systems has puzzled generations of social scientists, since they are particularly vulnerable to selfish rational actors who might exploit inherent asymmetries in the system (e.g. simply being the head-ender) or who might free ride on the provision of public infrastructure. As part of two related research projects that focus on how subtle social and environmental contextual variables affect the evolution and performance of institutional rules, several sets of experiments have been performed in laboratory settings at Arizona State University and in field settings in rural villages in Thailand and Colombia. In these experiments, participants make both a decision about how much to invest in public infrastructure and how much to extract from the resources generated by that public infrastructure. With both studies we find that head-enders act as stationary bandits. They do take unequal shares of the common-pool resource but if their share is very large relative to downstream participants' shares, the latter will revolt. Therefore for groups to be successful, head-enders must restrain themselves in their use of their privileged access to the common-pool resource. The comparative approach shows that this result is robust across different social and ecological contexts.

1. Introduction

Experimental studies of collective action in commons dilemmas typically focus on scenarios in which actors all share symmetric (or similar) positions in relation to the common-pool resource (e.g. Ostrom et al., 1994; Janssen et al., 2010). Naturally occurring commons dilemmas, however, often involve asymmetric relationships among participants. For example, in irrigation systems farmers at the tail-end or head-end can, and often do, experience differences in their capacity to influence collective action problems related to the maintenance of the irrigation system and allocation of water (Ostrom and Gardner, 1993). Given these conditions, it is often assumed that irrigation systems require a central authority to solve coordination problems. Wittfogel (1957), for example, 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, many examples of complex irrigation systems exist that evolved without central coordination (Hunt, 1988; Lansing, 1991; Ostrom, 1992).

The fundamental problem facing irrigation systems is how to solve two related collective action problems: 1) the provisioning of the physical infrastructure necessary to utilize the resource (water), and 2) the asymmetric common-pool resource dilemma where the relative positions of “head-enders” and “tail-enders” generate asymmetric access to the resource itself (water) (Ostrom and Gardner, 1993). If actors behave as rational, selfish economic agents, it is difficult to imagine how irrigation infrastructure would ever be created in the first place. Even if the initial problem of providing the infrastructure were solved, conflict may emerge because head-enders may not necessarily share the water with the tail-enders. The vulnerability of irrigation system performance to such behavior leads to the question of why so many self-organized irrigation systems exist and persist for so long (Hunt, 1988; Lansing, 1991; Ostrom, 1992). Experiments in social dilemmas have demonstrated during the last 20 years that the selfish rational choice model is not a good representation of human behavior to explain observed behavior (Camerer and Fehr, 2006). That cooperation occurs in social dilemmas is not a surprise, but what determines differences in the level of cooperation need to be explained.

A possible solution to the dilemma is the interdependency between upstream and downstream participants. Lansing and Miller (2005) discuss a game theoretical framework between upstream and downstream communities in Bali where the communities must share water and cooperate on pest control. The upstream communities are

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more concerned about pest outbreaks, while the downstream communities are more concerned about water shortages. This interdependency explains the cooperation between upstream and downstream communities.

Weissing and Ostrom (1991) explain the existence of effective coordination among farmers who are dependent on the efficiency and costs of mutual monitoring. In their work, Weissing and Ostrom assumed that a coordination system existed since farmers were assumed to steal water with a certain probability when it was not their turn. In the experiments reported here, we assume that such institutional arrangements do not yet exist at the start of the experiment; we assume only the biophysical reality of upstream and downstream participants.

The problem of asymmetric commons dilemmas goes beyond irrigation systems. In many actual common-pool resource dilemmas, there are differences among appropriators in their ability to access common-pool resources or public infrastructure. For example, the countries that are the main emitters of substances that enhance the greenhouse effect are not the same as those who experience the most severe impacts. The asymmetric commons dilemmas we study in this paper allow downstream participants to respond to the decisions of upstream participants by withholding contributions to public infrastructure maintenance in future rounds. In this case, even-though there is an asymmetry in power, participants are dependent on each-other.

The stationary bandit metaphor of Mancur Olson (1993, 2000) describes the challenges faced by a ruler in managing asymmetric power relationships. Specifically, the ruler acts as a stationary bandit who steals from (taxes) his or her subjects. However, if he or she steals too much without providing sufficient public infrastructure in return, the subjects increase the cost of stealing (revolt, evade taxes, etc.). This metaphor can be applied to irrigation systems in the sense that head-enders have first choice to use the water (i.e. can steal at will), but also need the help of the tail-enders to maintain the irrigation infrastructure. If head-enders do not provide a fair share of water, tail-enders may revolt by reducing their contributions to maintenance of the public infrastructure. Inequality in resource appropriation due to power asymmetries might occur, but it is bounded by the amount of inequality the tail-enders will tolerate. Unlike the Bali case described above, in this case the interdependencies are social rather than biophysical.

In our field and laboratory experiments aimed at studying these dilemmas, we found that upstream participants needed to be fair to downstream participants in order to maintain the efficiency of the public infrastructure. With efficiency, we refer to the long-term outcomes in a social dilemma. Groups in which upstream participants take equal water shares are more efficient, produce more common resources, in the longer term (multiple rounds). The field experiments were performed with villagers who have day-to-day interactions with one another in natural resource management contexts. The laboratory experiments were performed with undergraduate students at a US university. Although designed for different purposes, the similarities in the relationship between efficiency and equity in these different experimental treatments are striking. This suggests that this relationship may transcend biophysical context and the characteristics of the subjects taking part in the experiment.

The special issue in which this paper appears focuses on experiments involving common-pool resources in different contexts. The comparative analysis of findings from multiple experiments conducted here is an example of how we might leverage experimental work to explore the impact of contextual variables on what we might call core common-pool resource dilemmas and point the direction for new experimental treatments. By contrasting two experiments which have the same underlying asymmetric commons dilemmas but have different framings, participant populations, and methods of experimentation we are able to highlight some key regularities regarding social interactions in such situations. We first present the findings for the field and laboratory experiments individually and then proceed with the comparative analysis.

2. Asymmetric Commons Dilemmas

The detailed analysis of the results of the individual lab and field experiments discussed in this paper can be found in Janssen et al. (submitted for publication-a) and Janssen et al. (submitted for publication-b), respectively. The basic setup of the experiments is similar although the execution and nature of the subject pools is quite different. In both treatments, participants first decide how much of their initial endowment to invest in creating shared infrastructure through which a common-pool resource is made available. Next, participants decide how much of the common-pool resource to appropriate using the shared infrastructure they have just created. Note that because of the nature of the shared infrastructure, participants have asymmetric access to the common-pool resource. During an experiment, a group of 5 participants share a commonly held stock of public infrastructure (e.g. 5 land holders commonly own an irrigation system). If they all invest a significant amount toward the creation of public infrastructure, participants can, if they distribute the resource equally, double the earnings for each group member as compared to the case in which they invest nothing.

A key feature of public infrastructure projects such as irrigation systems is the existence of minimum thresholds of input intensity that must be exceeded before they may be carried out on a reasonable time scale. Thus, until a minimum investment threshold is exceeded, very little public infrastructure is produced. We capture this feature in the experimental contexts by assuming a sigmoidal relationship between investment and production of public infrastructure (the function $g(\cdot)$ below). The choice of the production function is guided by including the interdependency of upstream and downstream participants. In our experimental treatments, at least two persons need to invest a significant amount before the potential returns on investment in the public infrastructure becomes positive.

When public infrastructure is generated, the "upstream" participants have easier access to the common-pool resource thus made available (water in an irrigation system, bandwidth in a telecommunications network) and may be tempted to take more than an equal share relative to downstream users. Since multiple rounds are played in each experiment treatment, participants downstream can "sanction" those upstream for taking too much by reducing their own investment in the public infrastructure in subsequent rounds. The next section details the laboratory and field experimental designs and findings.

3. Experimental Set Ups

3.1. General

In both the lab and field experiments, there are five participants A, B, C, D and E. In each round of the experimental game, participants first receive 10 tokens. They then decide how many to invest in a public fund that generates the infrastructure which determines the amount of common-pool resource available for the whole group to share. Finally, each player decides how much to extract from the common-pool resource. In the lab, the infrastructure is bandwidth and the common-pool resource is data that can be downloaded. In the field, the infrastructure is irrigation canals and the common-pool resource is water. In both cases, participants occupy positions A, B, C, D or E from upstream to downstream where A has the first choice to harvest the common-pool resource, B the second choice, etc. Although the experiments in the lab and field are very similar, they differ in several respects in terms of their execution.

3.2. The Laboratory Set Up

In the lab treatments each token is worth $0.1. The production function for public infrastructure $g(y)$ depends on the sum of the tokens invested by individual players, y (e.g. if each player invests 8 tokens, $y = 40$). Given the discussion of the nature of this relationship above, we define $g(y)$ as:

$$g(y) = \frac{\omega y^{\gamma}}{y^{\gamma} + \eta^{\gamma}}, \tag{1}$$

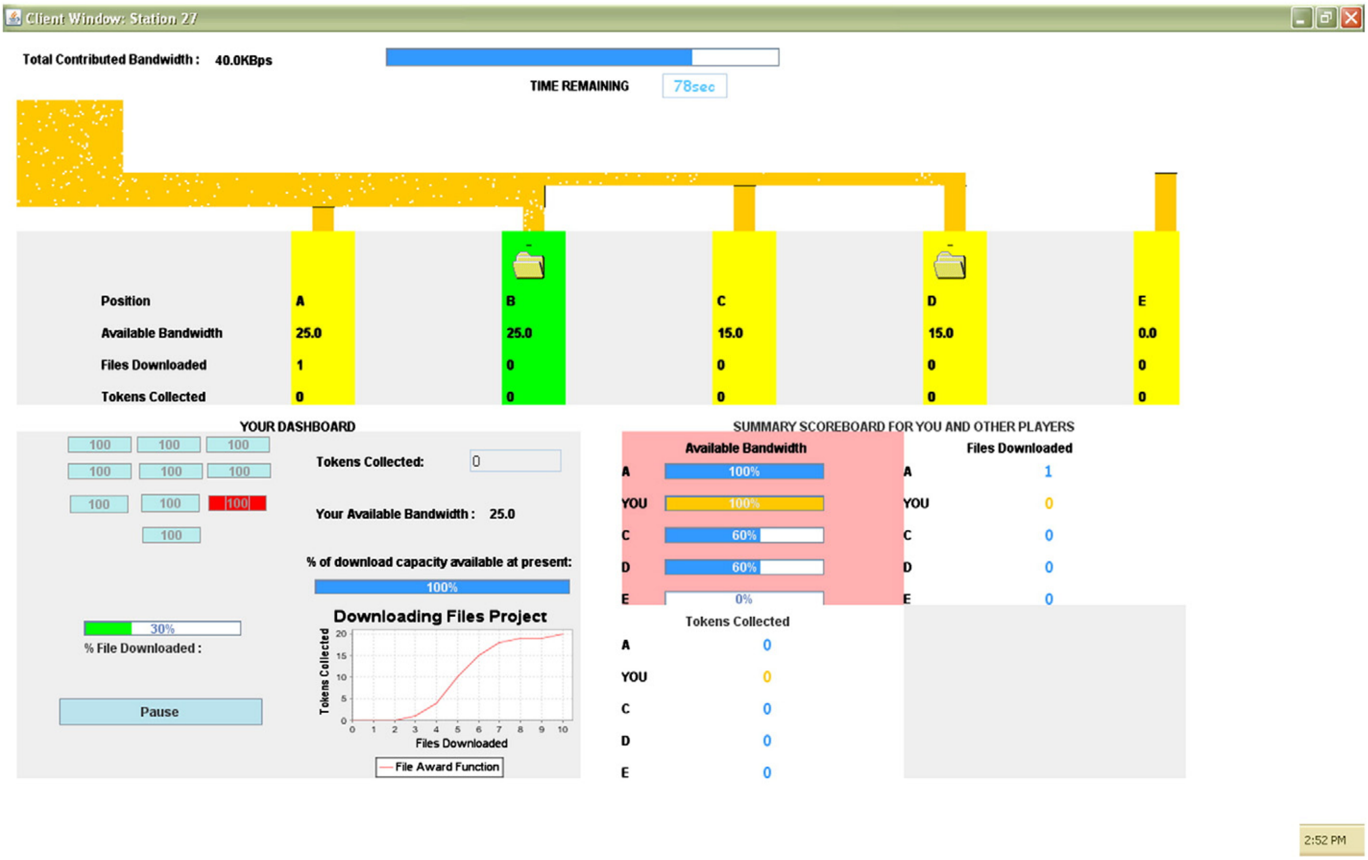
where the parameter $\omega = 40$ defines the maximum level of the public infrastructure. Note that in the experiment, $g(y)$ is rounded to integer values. The parameter $\eta = 30$ is the inflection point which defines the investment level for which 50% of the maximum level of public infrastructure is created. The parameter $\gamma = 10$ defines the steepness of the function near the threshold. Given these parameter choices, the production function exhibits increasing returns to scale for $0 < y < 30$ and decreasing returns for $y > 30$. This shape for a production function with a first stage of convex production followed by a concave portion is typical of many economic production functions in which initial investment in a fixed factor creates opportunities for economies of scale. Once the weight of the variable costs increase, however, decreasing marginal returns begin to dominate. This shape for the "total product" curve exhibits *the Law of Variable Proportions* (Cassels, 1936).

In order to avoid biasing participants for a particular or unfamiliar context, we chose not to present the experiment as an irrigation game but, rather, as a task more familiar to them. We describe it to participants as a game of downloading digital files, where participant A has priority access to the available bandwidth over participants B, C, D and E. In each round, after their investment decision is made, participants are informed how much each invested and how much total bandwidth is available for the 100-second downloading period that follows. During the downloading period, participants can click on buttons to initiate downloading of files (Fig. 1). They see an animation of a file downloading (white dots of "data" flow through the cable) and the time remaining in the round is shown at the top of the screen.

The public infrastructure (bandwidth) available in the downloading period is measured in terms of kilobytes per second (kb s). The maximum downloading speed for each player is 25 kb s. Thus, each player can download a maximum of 10 100 kb files during the 100-second period subject to bandwidth availability. Player A has first access to bandwidth (i.e. is upstream). Bandwidth not used by A is available to player B, and so on. For example, if a total of 40 kb s is available, and player A is downloading, 15 kb s would be available to downstream players. If B is chooses to download, her rate will be 15 kb s (less than her maximum possible of 25), and no bandwidth will be available to C, D, and E. Monetary returns resulting from file downloads depend on the function

$$f(x) = \upsilon \cdot \frac{x^{\beta}}{x^{\beta} + \alpha^{\beta}} \tag{2}$$

where x represents the number of files downloaded and $\upsilon = 20$ is the maximum number of tokens possible. The parameter α determines the number of file downloads required to generate 50% of υ ($\alpha = 5$ in our case). The parameter β defines the steepness of the function. Again, the shape of this payoff function is inspired by the irrigation dilemma. With too little water, yields drop off rapidly. Beyond a certain level, in this case 5, additional water generates decreasing marginal returns. If ten files are downloaded 20 tokens are earned.



Total Contributed Bandwidth : 40.0KBps

TIME REMAINING 78sec

Position	A	B	C	D	E
Available Bandwidth	25.0	25.0	15.0	15.0	0.0
Files Downloaded	1	0	0	0	0
Tokens Collected	0	0	0	0	0

YOUR DASHBOARD

Tokens Collected: 0

Your Available Bandwidth : 25.0

% of download capacity available at present: 100%

30%
% File Downloaded :

SUMMARY SCOREBOARD FOR YOU AND OTHER PLAYERS

	Available Bandwidth		Files Downloaded
A	100%	A	1
YOU	100%	YOU	0
C	60%	C	0
D	60%	D	0
E	0%	E	0

	Tokens Collected
A	0
YOU	0
C	0
D	0
E	0

Fig. 1. Screenshot of the experimental software used in the laboratory experiments. If participants wish to download a file, they can click on one of the 10 buttons with "100" (which means 100 kb). While the file is downloading, the button is red. After the file is successfully downloaded, the button changes to green. The source of the information flow is the box with white dots at the left. Information flow is represented by the dots moving through the "cable" from left to right. The bandwidth in this example is 40 kbs.

Table 1
Experimental design.

Label:	Treatment 1: Files can be downloaded in different periods	Treatment 2: Files need to be downloaded during an uninterrupted period
Number of Participants	6 groups = 30 participants	5 groups = 25 participants
Positions	A, B, C, D, and E	A, B, C, D and E
Length of time to download file	Depends on available bandwidth	Depends on available uninterrupted bandwidth

The total earnings of a player are given by the sum of the number of tokens not invested in the public infrastructure and the number of tokens earned by downloading files:

$$h(x, y) = 10 - y + \upsilon \cdot \frac{x^{\beta}}{x^{\beta} + \alpha^{\beta}}. \tag{3}$$

To compute the Nash strategy we assume players will download immediately if bandwidth is available. This leads to a situation in which it is in nobody's interest to invest in the public infrastructure. This leads to 10 tokens being earned by each of the players for a total of 50 for the group. The cooperative solution is much more complicated, and there are multiple equilibria. The maximum earning for the group is derived for various scenarios if a total investment is made of 37 or 38 tokens (e.g. 3 players invest 8 and 2 invest 7) in the public infrastructure. This can result in total earnings for the group of 104 tokens if participants coordinate their downloading behavior.

Before the participants can start the experiment, they go through a number of instructions and can only begin if all quiz questions are answered correctly. The experiment starts with 2 practice rounds which do not count for earnings followed by 10 rounds for monetary returns. Before each round the players are allowed 60 s to exchange text messages among those within their group.

We used two treatments in this study (Table 1). In the first treatment a participant can start and stop downloading a file as they please. In the second treatment, the download of a single file can't be interrupted. Partly downloaded files will be lost if an upstream participant utilizes all available bandwidth, completely disrupting the downloading of downstream players. The different treatments reflect increasing complexity of coordinating access to bandwidth and roughly correspond to biophysical realities in irrigation systems, such as seasonal variations of water availability, and different crop varieties.

3.3. The Field Set Up

The importance of micro-situational variables and the nature of the community are often stressed in the study of institutions (Poteete et al., 2010). This raises obvious questions regarding how these considerations affect the outcomes in the laboratory experiments described above. To explore these questions, we compared the laboratory results with outcomes from the irrigation games we performed in six rural villages in Thailand and Colombia (three in each country). Residents of these villages engage in natural resource appropriation on a daily basis.

When necessary, permission to perform experiments was requested of, and granted by, the heads of villages. The experiments were conducted during the first 6 months of 2007. Typically four days of experiments in each location were followed by in depth interviews with a sample of relevant stakeholders from the village. In each of the six villages, the irrigation game was conducted with 4 groups of 5 people resulting in a total sample of 120 individuals.

Although participants in each group may have known each other, neither were they allowed to communicate, nor did they receive any information about the decisions of others during the experiment. Only aggregate outcomes of their decisions were reported to the group. Assistants were available during the experiments for those participants who might have had difficulty with reading and/or arithmetic. After the instructions were presented to the group and the practice rounds were completed, participants played 10 rounds (although they were not told the number of rounds in advance). These rounds were followed by 10 additional rounds played under a different set of rules determined by a group vote. Given our interest in the impact of intrinsic asymmetries in incentives on the functioning of the game, our comparative analysis here focuses on the first 10 rounds of the baseline game. See Janssen et al. (submitted for publication-b) for the full analysis of the later rounds.

Table 2
Water production as a function of units invested in public fund in the laboratory experiments.

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

Participants 18 years and older were recruited both via word of mouth and through flyers posted throughout the village. A special effort was made to recruit adults from households engaged in resource appropriation activities particular to their village. Only one member of a family was allowed to participate in each session. At the end of the series of experiments in each village, a handful of people were selected from the participant pool for in-depth interviews. Every effort was made to select a representative sample of the community. Finally, at the end of the week, session was organized to discuss the experiments and their relation to actual natural resource use.

As in the laboratory set up, each token had a monetary value for the player and, in this case, was equal to the value of a unit of water extracted. Table 2 shows the relationship between the water provision generated and the total investments of the five participants in the public infrastructure. After the public infrastructure is generated, a common pool resource is provided. Participant A has the first choice how much to take from the resource. The amount that is left over is turned to participant B, who can decide how much to take, etc. until E can decide how much of the remaining resource to take. The Nash equilibrium for a non-repeated game is that nobody invests in water provision and each participant receives 10 tokens (group earnings = 50 tokens). In the cooperative equilibrium, each participant invests 10 tokens in the public infrastructure. This produces 100 units of water (income) for the group in each round.[1] How these water units are distributed among players depends on their position and the appropriation decisions of upstream players.

4. Experimental Results

4.1. In the Laboratory

The experiments were performed between November 2007 and February 2008 at Arizona State University. Participants were recruited from a database composed of undergraduate students willing to participate in experiments from all majors. Invitations were sent to a

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[1] In fact, a slightly superior solution of 104 tokens can be achieved (See Fig. 6) when total group investment is 46 tokens and the maximum of 100 water units is generated. Such a solution, however, would require a non-symmetrical allocation of contributions and earnings.

random sample of the whole population a few days prior to a scheduled experiment.

Tables 3 and 4 summarize the basic statistical analysis of the data resulting from the experimental treatments. The analysis shows that participants invest a considerable amount of their token endowments in public infrastructure. The data also confirm that 'downstream' participants invest somewhat less than those upstream. The number of files downloaded is quite unequally distributed; position A downloads about twice the amount as E. These differences are significant ($p < 0.01$) in the default experiment between person A and C, D and E, and between B and E. For the experiments which require uninterrupted bandwidth for individual file downloads only downloads between person A and E differ significantly. These investment and downloading patterns lead to considerable earnings inequality between upstream and downstream participants. Participants in position E, for example, received even less than the Nash equilibrium of 10 tokens.

The statistical analysis also shows that the level of public infrastructure generated increases over time (Fig. 2) as does the level of earnings per person per round. Initially, earnings were about 12 tokens per round and, over time, increased up to 15 tokens per person.

Inequality in file downloads is most pronounced at the beginning of the experiment, lessening after a few rounds have been played. Interestingly, inequality among contributions is lower than that between earnings, and does not change significantly during the experiment. The uninterrupted bandwidth treatment leads to similar gini coefficients compared to the less challenging default experiment. Later we show that the experiment requiring uninterrupted bandwidth for file downloads requires greater need for coordination and fair distribution of files in order to maintain investment in the public infrastructure.

Figs. 3 and 4 show the level of group investment and earnings in relation to the optimal cooperative solutions for each treatment. Note that for determining the earnings we add the earnings from water units harvested to the amount of tokens not invested in public infrastructure. We see, not surprisingly, that it is more difficult for participants to coordinate when a partly downloaded file can be lost. We also see that a typical strategy, although it does not lead to the maximum output for the group, is to invest the maximum number of tokens in the public infrastructure. In the second treatment (Fig. 4) we see only rarely do group earnings approach the level of the cooperative strategy. Positive reaction times and lost files due to bandwidth interruption result in fewer file downloads by downstream players.

We used linear multilevel analysis to estimate the effect of inequalities in contributions to public infrastructure and the number of files downloaded in a given round on the level of group contribution to public infrastructure in the *next* round and found there is a negative relationship, especially for the unrestricted bandwidth treatment (Table 5).

4.2. In the Field

The average age of our participants was 37 years (Std. dev 13.8) and 39% were females. About two thirds reported living in their village for their entire life. The average (and modal) household size was 5 individuals, with 5% having 2 or less members and 10% having 9 or more. The education level of the participants also varied: 5% had no formal education, 28% had completed some or all of their primary education, 53% had secondary education, and only some 15% had received technical or university training. About 81% reported owning some land. At the end of the experiment each participant was paid in cash and in private according to the number of tokens earned in the game plus an additional show up fee. On average, each player earned the equivalent to 1–2 days wages for her participation in a 2- to 3-hour session.

Table 3
Average numbers per round for the default experiments (standard deviation) in the laboratory experiments.

	Tokens invested	Files downloaded	Tokens earned
A	8.75 (0.83)	6.95 (2.31)	16.48 (3.94)
B	8.48 (1.09)	6.80 (1.72)	16.85 (2.61)
C	8.48 (1.11)	5.42 (1.36)	13.35 (4.21)
D	7.78 (2.06)	5.42 (2.38)	14.40 (3.77)
E	6.72 (3.51)	3.22 (2.20)	9.4 (3.70)

Table 4
Average numbers per round for the experiments where uninterrupted bandwidth availability is required during a file download (standard deviation).

	Tokens invested	Files downloaded	Tokens earned
A	9.08 (0.95)	5.44 (1.23)	13.68 (3.18)
B	9.04 (1.56)	5.78 (1.74)	14.22 (3.15)
C	7.22 (2.56)	4.32 (1.95)	11.94 (2.99)
D	8.60 (1.74)	4.62 (1.76)	11.30 (2.38)
E	7.24 (2.90)	3.42 (1.63)	7.96 (2.49)

Fig. 5 shows the average levels of irrigation infrastructure generated by the contributions of all players. From the start of the first stage, the Thailand sessions show higher levels of contributions. The decrease over time of such contributions, consistent with baseline voluntary contributions in public goods experiments, seems to be present, especially for the Colombian sessions.

Fig. 6 shows the group earnings in relation to group investments. Compared to the laboratory experiments (Figs. 3 and 4), there was no significant loss of the resource since the actual group earnings are close to the line of maximum group earnings for each level of group investments. About 2% of the generated common pool resource was not collected by the group. In the laboratory experiments it was more difficult to harvest the maximum number of tokens from the common pool resource since the timing of downloading files needed to be tightly coordinated in real-time.

In Fig. 7 we report the average contribution and resource appropriation levels in each of the locations in the watershed. We see a clear inequality between appropriation levels of those upstream and those downstream. Participants at position E receive less than 10 units per round (the level of returns if they invest nothing in irrigation infrastructure). Clearly, under this baseline condition, downstream players E are subsidizing those upstream by contributing about half of their endowment (See Fig. 7) and obtaining a very small return from it. Meanwhile, upstream participants are obtaining a large return on their initial contributions which are not substantially larger than those made by downstream participants (Fig. 7).

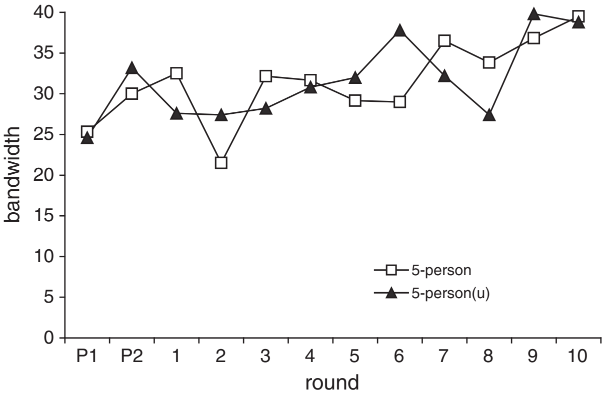

Fig. 2. Average level of bandwidth for the two treatments in the lab experiment.

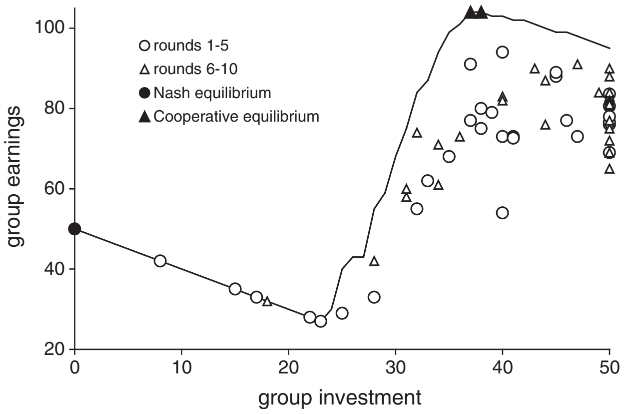

Fig. 3. The relationship between group investment and group earnings for each round of the default case in the laboratory. A distinction is made between data shown from first half and second half of the experiment.

Table 5
Regression results of number of tokens invested in bandwidth by groups in the laboratory experiments. Between brackets are the standard deviations. ***P<0.01; **P<0.05; *P<0.1.

Dependent variable: Tokens invested	Treatment 1: Files can be downloaded in different periods	Treatment 2: Files need to be downloaded during an uninterrupted period
Constant	35.223*** (3.558)	48.895*** (3.346)
Round	1.444*** (0.393)	0.456 (0.436)
Gini contribution (t−1)	−14.666*(7.827)	−35.863*** (5.774)
Gini collection (t−1)	−8.573 (6.060)	−32.916*** (7.818)
−Log likelihood	188.761	154.454
N	54	45
Variance components		
Group component	4.440 (2.221)	0.0000
Individual component	7.359 (0.784)	7.489 (0.789)
χ^2	2.36 (p=0.0621)	0.0000 (p=1.0000)

We performed a linear multi-level analysis to test, as in the laboratory experiments, how inequality affects contributions to public infrastructure. The analysis suggests that inequality in contributions to public infrastructure in the previous round reduces contributions in the current round. Considering various demographic and survey data, we find that Thai participants invest 2 tokens per round more than Colombian participants and that when the average age is higher, this tends to lead to lower contributions. We did not found significant factors of gender, education and trust at the group level on the level of contributions and inequality of contributions and extractions.

When we examine what contributes to inequality in contributions to the public infrastructure and appropriation of resources at the group level, we find that there is a strong "learning" effect. As the rounds progress, *ceteris paribus*, groups will increase their inequality in both appropriations and contributions. This inequality will increase slower with higher contribution levels to the public infrastructure.

5. A Comparative Analysis

Both the laboratory experiments and field experiments used asymmetric commons dilemmas where 5 participants first needed to decide how much of their endowment to invest in the public infrastructure and then, in order of their access, how much to collect from the generated common-pool resource. We recognize that the small number of participants in each group makes it less challenging to overcome the collective action problem compared to larger groups although the challenge of heterogeneous groups remains in our study (Olson, 1965). The circumstances and designs of the experiments were quite different although there is a form of external validity in each case in terms of familiarity of the subjects with the task. The laboratory experiments involving undergraduate students from Arizona State University were computer based, participants did not know other persons in the group but could exchange text messages, and the problem was translated into a real-time downloading game. The field experiments were performed with villagers in rural areas in Colombia and Thailand using paper and pencil. The participants knew each other but could not talk with each other during the experiment and the experiment was framed as an irrigation game.

If we look at the level of public infrastructure generated over time (Fig. 8), we see that initially the levels were similar. However, the level in the laboratory experiments increased over time while in the field experiments it declined somewhat. This is not surprising since participants in the laboratory experiments could chat with each other and this has been found to increase the level of cooperation (Hackett et al., 1994).

We see that the downstream participants in the laboratory experiments invest less than the upstream participants (Fig. 9). An explanation for this can be found in the data from the text communications during the chat period. Downstream participants were allowed to invest a bit less to make up for their lost earnings in previous rounds when they did not get sufficient opportunity to download files. In some cases downstream participants did not invest a significant amount in the generation of public infrastructure as a protest against lack of downloading opportunities in earlier rounds. The average contribution among the villagers was insensitive to the position of the participant, but the average contribution of a group did respond to inequality in contributions and earnings observed in the

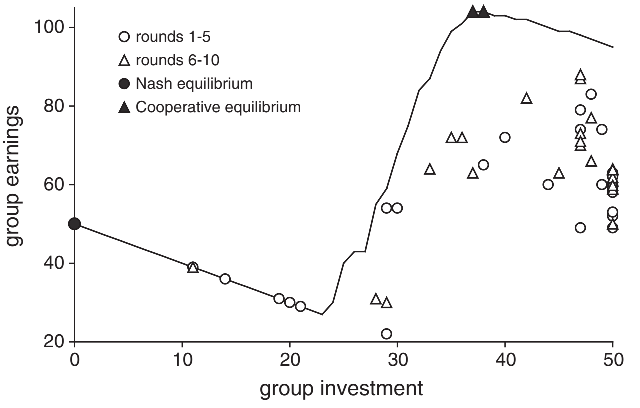

Fig. 4. The relationship between group investment and group earnings for each round of the experimental treatment requiring unrestricted bandwidth for successful file downloads. A distinction is made between data from first and second half of the experiment.

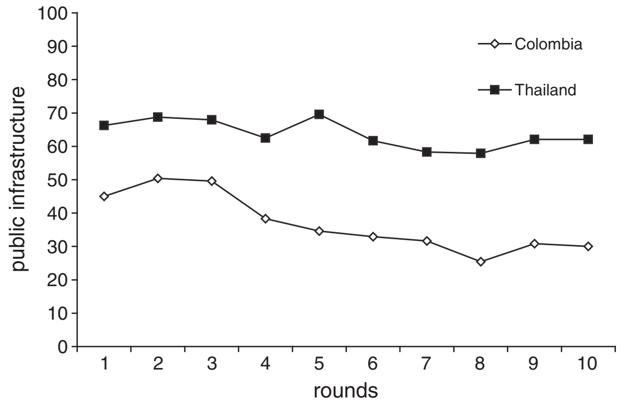

Fig. 5. The average level of public infrastructure generated in the field experiment.

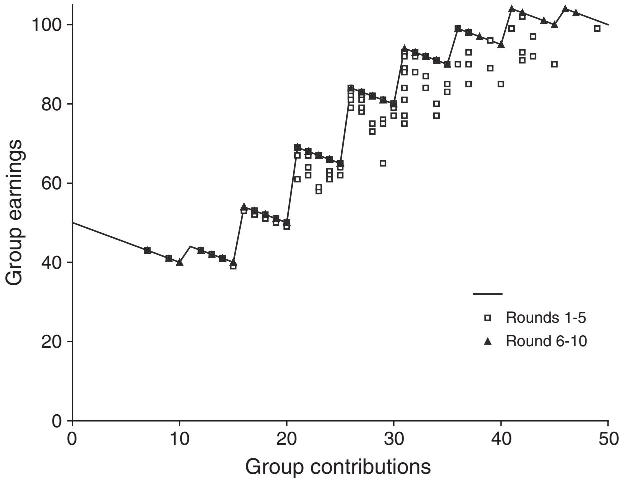

Fig. 6. The relation between the group investment and group earnings for each round of the field experiments. A distinction is made between data from the first and second half of the first 10 rounds of the experiment.

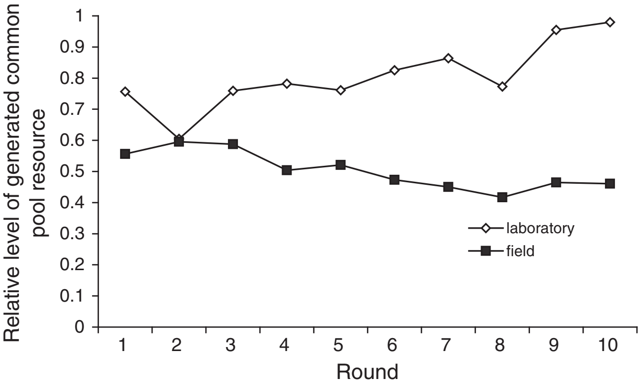

Fig. 8. Scaled average level of resource per round for laboratory and field experiments.

previous rounds (Table 6). More unequal contributions or appropriations in the previous round hindered contributions in the next round.

The level of resource appropriation is much more skewed in the field compared to the laboratory (Fig. 10). In the laboratory there is inequality initially but as the rounds progress, participants develop rotation systems to reduce earnings inequality. In the field, inequality persists over the rounds, which might be caused by lack of communication. The main response to inequality is a reduction in contributions to the public infrastructure.

As an illustration, we show the public infrastructure levels and the gini coefficients for resource appropriation for the worst and best groups in the field experiments (Fig. 11). The best group has a low resource appropriation gini coefficient (around 0.2) during the whole experiment. Moreover, the upstream participant takes less than an equal share from the resource. Taking 15 units of water from a generated resource of 95 units of water signals commitment to the other group members. This commitment is rewarded in subsequent rounds by continuous large investments by downstream participants. In contrast, in the worst group the upstream participant takes almost the entire resource if a positive amount is generated. This leads to a decline in investment levels. Despite different attempts by the group to initiate investment in public infrastructure in order to generate a common-pool resource, this fails in every instance due to the selfish behavior of the participant in position A.

From the statistical analysis we learned that contributions to the public infrastructure are, in both types of experiments, significantly related to the inequality of contributions and earnings from resource appropriation in the previous round. Inequality leads to lower contributions, and hence to a reduction of the earnings for the whole group in the longer term.

6. Conclusions

Here we have reported and compared the results of two sets of experiments performed with asymmetric commons dilemmas in the laboratory and the field. Both sets of experiments involve a decision regarding contributions to public infrastructure and a subsequent decision regarding extraction of the common-pool resource made available by the infrastructure. This creates a privileged position for those located at the start of the sequence. Despite the very different participant pools and experimental context, we find in both sets of experiments that upstream participants take more of the common-pool resource than downstream participants. Given that each task is sufficiently familiar to the respective subject pool (students downloading files and villagers extracting water), the parallels between the two experiments should be of value. There is a negative relationship between inequality of resources appropriated by participants in the previous round and investment in public infrastructure in the present round. This suggests that there is a fundamental balance between inequality and efficiency. The chat data from the lab experiments indicate that downstream participants threaten to reduce investment levels if they do not get more from the common-pool resource. To investigate more specifically how much inequality participants tolerate we may explore the use of strategy methods, where participants compose strategies for different situations that reveal their preferences.

In asymmetric situations, how much inequality do the less privileged accept before reducing their investments in the public infrastructure? This is the core question for the stationary bandit —

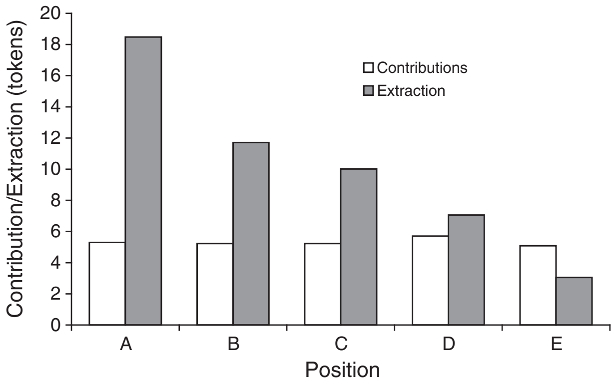

Fig. 7. Average earnings per round of the field experiment for the different positions.

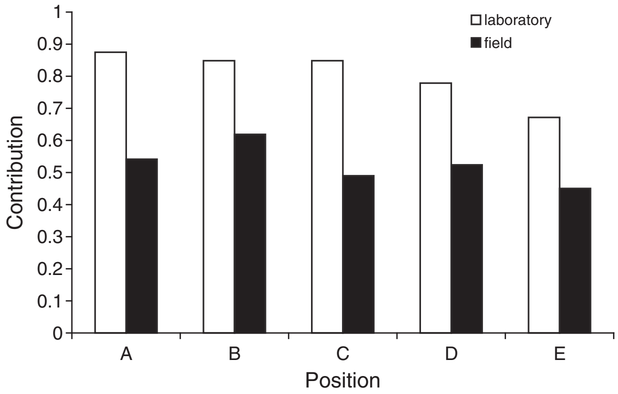

Fig. 9. Scaled level of contributions for the different positions.

Table 6
Regression results of number of tokens invested in water resource by groups in the field experiment. Between brackets are the standard deviations. ***P<0.01; **P<0.05; *P<0.1.

	Contribution	Gini contributions	Gini collection
Constant	56.759*** (13.930)	0.303* (0.173)	−0.624 (0.423)
Country (Colombia = 0)	13.728** (5.718)	−0.030 (0.069)	−0.310* (0.165)
Round	−0.348** (0.141)	0.007*** (0.001)	0.015*** (0.002)
Irrigation village	−4.497* (3.439)	−0.007 (0.041)	0.101 (0.100)
Gini contributions (t − 1)	−14.010*** (4.627)		
Gini appropriations (t − 1)	−2.051 (2.673)		
Contribution		−0.007*** (0.001)	−0.003** (0.001)
Avg age	−0.445* (0.215)	0.003 (0.003)	0.015** (0.006)
Avg fraction women	7.966 (5.156)	−0.015 (0.063)	−0.084 (0.160)
Avg education	−1.857 (2.490)	0.012 (0.030)	0.100 (0.077)
Avg married	−4.046 (6.915)	0.024 (0.084)	0.235 (0.216)
Avg trust[a]	−16.518 (17.463)	−0.078 (0.211)	0.354 (0.518)
−Log likelihood	626.420	266.846	183.745
N	212	240	233
Variance contributions			
Individual	4.508 (0.235)	0.0631 (0.0031)	0.0840 (0.004)
Session	4.862 (1.062)	0.0596 (0.0121)	0.1588 (0.029)
Village	1.607 (3.016)	0.0176 (0.0290)	0.0297 (0.064)
Country	1.168	0.0153	0.0208
χ2	64.36 (p = 0.0000)	69.86 (p = 0.000)	215.12 (p = 0.0000)

[a] Trust is a composed value between 0 and 1 based on a series of survey questions. More information can be found in Janssen et al. (submitted for publication-b).

the ruler who must determine how to balance the use of resources for her own ends and the use of resources to provide public goods required for political support. This is also true for democratically elected officials whose actions are always constrained by political considerations. Given the ubiquity of this problem, locating such thresholds is an important area for future research. The tolerable level of unequal appropriation by head-enders is probably dependent on the specific conditions of the production function, the group size and the benefits and costs of appropriation and contribution to providing the public good.

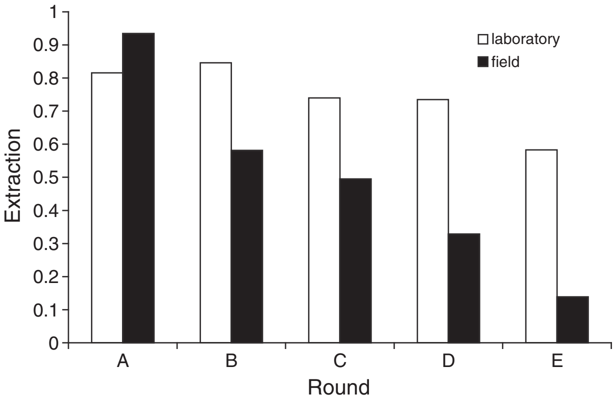

Fig. 10. Scaled level of earnings resulting from appropriation of the common-pool resource for the different positions.

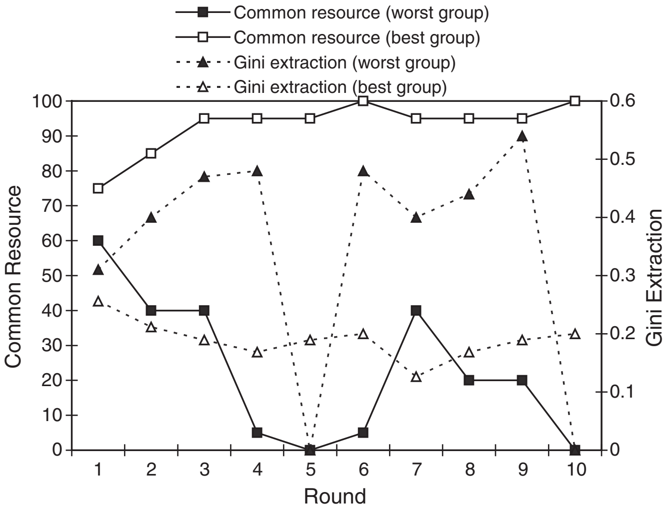

Fig. 11. The generated common-pool resource and the gini coefficient for resource appropriation for those groups that had the best and worst performance of all 24 groups in the field experiments.

The role of regulatory agents and institutions is also an important open question. Given the asymmetry of strategies by the players, should institutions and their enforcers work on restraining head-enders in their appropriation levels or on promoting contributions among those downstream? Of course both strategies would benefit the group, but under limited resources which could be more cost-effective? Weissing and Ostrom (1993) show that the effectiveness of formal guards depends on the self-monitoring activities of the other participants, the costs of monitoring and rewards for the guards for their services. The biophysical context can affect these costs of enforcements and abilities of groups to establish formal institutional arrangements.

While it is commonly understood across many social science fields that power asymmetry is an important driver in social systems, common-pool resource experiments have not yet paid much attention to them. We suggest that the concept of roving and stationary bandits would be a helpful framework to investigate such asymmetries (Olson, 2000). The possibility of becoming a stationary bandit in our experiments was randomly assigned, and there was considerable attention paid by participants to the equality of resource appropriation among the players. Such equality considerations might be reduced when asymmetrical positions are not randomly allocated, but emerge endogenously (Muehlbacher and Kirchler, 2009).

Inequality of access does not preclude cooperation, but it can hinder it. Whether or not this is the case is sensitive to the actions of the more privileged resource users, usually located upstream in the kind of sequential collective action problems studied here. For groups to do well, upstream participants need to restrain themselves to earn the commitment of downstream participants to invest in the production of public infrastructure that generates the common-pool resource and therefore provide enough resources for everyone. The comparison here shows that this finding is independent of several contextual variables, such as expertise of participants, real-time computer game versus paper-and-pencil experiment, anonymous student groups versus known community members, no communication versus text chat, framing of the experiment and suggests further research regarding subtle contextual variables that may have a stronger effect.

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