TURFS IN THE LAB

INSTITUTIONAL INNOVATION IN REAL-TIME DYNAMIC SPATIAL COMMONS

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ABSTRACT

Using a real-time, spatial, renewable resource environment, we observe participants in a set of experiments formulating informal rules during communication sessions over three decision rounds. In all three rounds, the resource is open access. Without communication, the resource is persistently and rapidly depleted. With face-to-face communication, we observe informal arrangements to divide up space and slow down the harvesting rate in various ways. We observe that experienced participants, who have participated in an earlier experiment where private property was used as one way of controlling harvesting in this renewable resource environment, are more effective in creating rules, although they mimic the private-property regime of their prior experience. Inexperienced participants need an extra round to reach the same level of resource use, but they craft a diverse set of novel rule sets.

KEY WORDS • common-pool resources • laboratory experiments • communication • institutional innovation

Introduction

The existence and continuity of many self-organized, common-property regimes are well documented (for overviews, see NRC 1986, 2002), but three questions continue to puzzle researchers who are interested in the governance of common-pool resources (CPRs). One question relates to the initial process of self-organization. Few researchers are able to observe the discussions that enable a set of resource users to agree to limit their own resource use. By coming to an agreement, a group solves a second-level

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social dilemma (that may then help to solve the first-level social dilemma of regulating the CPR). How do they arrive at an agreement?

A second question relates to why self-organized resource appropriators tend not to limit harvesting to a specific quantity of resource units, while the allocation of quantities of resource units is frequently used by terrestrial common-property regimes (Schlager 1994). Since Individual Transferable Quotas (ITQs) are recommended as an optimal allocation device for fisheries (Anderson 1995; Baumol and Oates 1988), this is a particular puzzle. A third question relates to why simply allowing face-to-face communication is such a powerful technique for enabling subjects facing an experimental common-pool resource to achieve higher joint outcomes (Ostrom and Walker 1991). We will discuss these three questions in reverse order.

Why Communication May Work to Solve Collective-action Dilemmas

Renewable resources are generally overharvested in the field and in the lab when *no rules* limit who can harvest or how much they can harvest (an open-access situation) (Berkes et al. 2006; Ostrom et al. 1994). In experimental settings, simply allowing communication has repeatedly been shown to improve outcomes (Sally 1995; and articles cited below). Given the results of large numbers of experiments on common-pool resources – and social dilemmas more generally – we now understand that the model of human choice initially used in game theoretical analysis, positing human choice based entirely on short-term material returns to self, is not adequate for predicting behavior in social dilemmas (Cox et al. 2007; Fehr and Gächter 2000; Ostrom 1998; Ostrom et al. 1994). The narrow self-interested model of human behavior predicts behavior well in highly competitive situations such as an open market for private goods or in competitive elections.

In repeated public good experiments, initial behavior tends to be more cooperative than predicted (Goetze and Orbell 1988; Isaac et al. 1985; Orbell and Dawes 1991). Without communication, however, initial levels of cooperation tend to decline rapidly (Davis and Holt 1993; Isaac et al. 1984). Face-to-face communication reverses this downward cascade (Cardenas et al. 2004; Hackett et al. 1994; Ostrom and Walker 1991).[1] Why communication has this positive effect is a substantial puzzle.

Debate exists as to why communication alone leads to better results (Buchan et al. 2006). In some experiments with a relatively simple payoff function, research has shown that increased performance with communication is not due to better understanding of the experiment (Edney and Harper 1978; Kerr and Kaufman-Gilliland 1994). In the CPR experiments, where the more complex, quadratic harvesting equation originally posited by Gordon (1954) has been used for the payoff function, subjects spent time initially making sure they understood what harvesting level is the equivalent of the group optimum and how to allocate that to individuals (Ostrom 2006; Simon and Schwab 2006). The review by Shankar and Pavitt (2002) suggests that the voicing of commitments and the development of group identity and norms seem to be the best explanation from previous experiments. In the experiments reported herein, communication plays an important role in helping participants figure out a good strategy together as well as building commitments so as to achieve far better outcomes than those achieved in repetitive situations without communication.

Why Self-organized Fisheries Tend to Allocate Space Rather Than Quantity

Field research has generated a rich and extensive case study literature that describes a wide variety of innovative rules that are locally crafted to govern where, when, and how resource units should be harvested from common-pool resources. Among irrigation, forestry, and pastoral systems, one finds a variety of mechanisms that allocate a specific quantity of resource units (e.g., water or firewood) to local users (Gibson et al. 2000; McCarthy 2004; Netting 1981; Shivakoti and Ostrom 2001). In regard to inshore fisheries, on the other hand, two meta-analyses of case studies of inshore fisheries that had developed rules for allocating use rights found *no* self-organized, inshore fisheries that allocated rights to a *quantity* of fish (Schlager 1994; Wilson et al. 1994). A wide variety of rules do exist that allocate territories in a manner that resembles the allocation of private-property rights to land. Further, fishers have developed a diversity of methods for designating territories based on their local knowledge of specific attributes of their local resource.

The term 'territorial use rights in fisheries' (TURFs) has been applied to this old and well-established tradition among indigenous fishers (Christy 1982). Fishers along the coast of Newfoundland (Martin 1979) and Maine (Acheson 2003) are famous for their use of territories as their primary allocation mechanism. Among beach seine fishers in the Caribbean, a number of self-regulating management systems using a TURF system have been well documented (Brown and Pomeroy 1999). Gelcich et al. (2007) document the processes and financial outcomes achieved under a Chilean government-sponsored TURF program initiated in the 1990s.

> The TURF may be defined as a system in which the community of beach seine users allocates the fishing opportunity at designated fishing sites on a time specific basis. The TURF system may be characterized as: site-specific in that the fishing opportunity is usable at specific sites; gear-specific in that a single type of gear, either threaded or monofilament seine is allowed to operate in the TURF; time-specific in that either specific real time or specific time limiting conditions for use of the fishing opportunity are provided for; but species nonspecific in that no limit is placed on the type of fish species that may be harvested. &ellipsis; These informal systems of resource use and management have evolved over the decades and demonstrate wide acceptance, legitimacy, and effectiveness within individual communities. (Pomeroy 2001: 124–5)

In contrast to these territorial allocations, many scholars have advocated the allocation of a quantity of resource units – an Individual Transferable Quota (ITQ) system – as the preferred method of solving the problem of overharvesting of resources (see Tietenberg 2002 for a good review of the use of ITQs). The dominant use of TURFs, rather than ITQs, has been a puzzle to scholars interested in common-pool resources. Wilson (2002) provides an initial answer to the puzzle by stressing the complex nature of fisheries and the extreme challenge of measuring the quantity of fish at any stage of development. While the amount of water, trees, and fodder on a pasture may be roughly estimated given a variety of visual clues, the amount of fish available is extremely hard to measure – particularly without some of the technological advances achieved only very recently. Thus, fishers through the ages have been faced with the problem of allocating a highly changeable resource that does have spatial characteristics even though measuring the quantity available is particularly challenging.

How Do Participants Solve Collective-action Problems?

The third question we explore in this study is the process of solving collective-action problems. The participants in these experiments share a common renewable resource that is spatially explicit. We allow the participants to communicate about how they might improve their performance in harvesting the resource (in other words, how they can earn more money in the experiment). We will see that face-to-face communication enables them to discuss the common problem they are facing and to explore the feasibility of diverse methods for solving collective-action problems. Given the structure of the experiment, we observe that the types of informal rules participants propose are largely based on the spatial allocation of territories for individual use of the resource.

A Virtual, Dynamic Spatial Experiment

The experimental environment we have designed for this study is much richer in terms of the decisions that participants can make than previous CPR experimental environments. A group of participants interact in real time to harvest tokens from a spatially explicit renewable resource. Participants move their avatars on the screen and make decisions on where to go on a grid to harvest tokens and how fast to move on the screen. Therefore, they make dozens of decisions during the few minutes of each round in an experiment instead of one decision per round (and perhaps 25 to 30 total decisions in the full experiment). Subjects can make many hundreds of decisions during an experiment – if they find methods to allocate either space or time to one another so they do not overharvest the resource and face an empty screen.

Due to the richness of the experimental environment, it is suitable for studying how subjects innovate rules in a complex environment. While they cannot make an estimate of the total quantity of resource units available, they can see resource renewal patterns. This enables them to craft innovative rules for allocating space and time to one another as a way of using the common resource. Thus, this experiment enables us to examine institutional innovation in a virtual, dynamic resource. Participants developed various rules that mainly focus on dividing the 'turf' in equal amounts or the timing of their harvesting.

We will show that communication among participants increases performance in an open-access situation, even more than a clear assignment of 'private property' without an open discussion of rule options with one another. Furthermore, communication leads to more effective results in groups of experienced participants. To our surprise, learning who the other participants are in a group is less important than an open exchange of possible solutions to the overharvesting problems within a larger group. Open exchanges do appear to affect the learning that a group of participants can achieve in contrast to relying primarily on one's own learning without an exchange with others (see Golman and Page 2006).

A fourth key point that we will show is that communication enables participants to find aspects of their own environment in the laboratory that are useful in making workable rules and monitoring each other's conformance. Researchers have found that users of a common-pool resource tend to identify prominent aspects of the resource they are using that make it easier to monitor and regulate use patterns. Sometimes they create a spatial map using specific landmarks that are very obvious as ways of specifying territorial boundaries rather than some arbitrary, neat, rectangular array imposed by survey markers (Berkes 1986; Cordell 1984). Sometimes the natural layout of a territory makes entering a particular resource at a specific location more obvious and easier to monitor than others (Janssen and Ostrom 2006). The array of specific markers, locations, seasons of the year, and type of harvesting equipment that users themselves integrate into their rules to organize harvesting activities and reduce the costs of monitoring and sanctioning each other's use patterns is immense in its variety (see Digital Library of the Commons, http://dlc.dlib.indiana.edu/).

Experimental Design

The experiment[2] is designed to learn more about how communication affects the decisions of participants in a real-time spatially explicit commons. While we know that cheap talk increases cooperation, we were especially interested in the type of strategies participants developed. Did experience in earlier experiments enable individual participants to learn about this environment and make better decisions?

In the experiment, groups of five participants share a renewable resource that grows on a 20 × 50 spatial grid of cells. They can collect tokens during three rounds, each of which lasts approximately four minutes. The length of a round is not known to the participants but is programmed as a random variable to average four minutes. Participants harvest a green token by moving their virtual avatar's location on top of the token. They move their avatar by pressing the arrow keys (left, right, up, and down). Each token harvested is worth $0.01.

The resource renewal rate is density dependent. As the number of green tokens around an empty cell increases, the probability increases that in the next time step a green token will appear on the empty cell (see Figures 1 and 2). The probability p_t is linearly related to the number of neighbors: $p_t = p*n_t/N$ where n_t is the number of neighboring cells containing a green token, and N the number of neighboring cells (N = 8 because we use a Moore neighborhood). The parameter p is defined in such a way that the renewal of the resource is quick enough to be observed by the participants, but sufficiently slow that the participants experience a dilemma between immediate, individual benefits and longer-term, group benefits. If participants quickly collect as many tokens as they can, there will be no tokens remaining on the screen (Figure 2). Once every token has been harvested, no further opportunity exists for any new tokens to be created. Participants do not receive information on the individual earnings of other participants in the group.

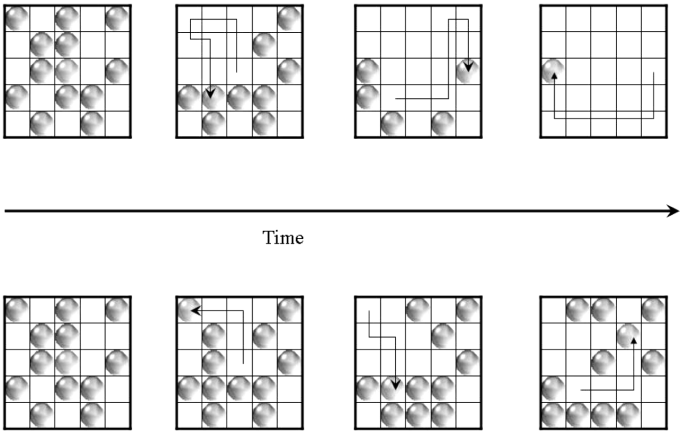

Figure 1. Four snapshots of two harvesting strategies by two different types of participants in a hypothetical situation of a 5×5 resource. On the top row in the figure above, the participant moves their avatar eight steps per time period. There is almost no time for regeneration, and a participant following this strategy overharvests the resource by the fourth snapshot. On the bottom row, the participant moves their avatar only four steps per time step, and the resource has time to regenerate since enough tokens remain. After four time steps, the resource has not significantly declined and a participant following this strategy can continue to harvest for many more time steps.

Figure 2. Screen view of the renewable resource as observed by a participant, where the green tokens are the potentially regenerating resource units, black cells are empty cells, and the yellow dot is the participant's avatar. Blue dots are the locations of the four other agents.

Table 1. The four experimental treatments

Treatments (groups)	*Round 1*	*Discussion*	*Round 2*	*Discussion*	*Round 3*
T1. Inexperienced participants (I1–I4)	Open access	None	Open access	None	Open access
T2. Inexperienced participants (IG1–IG6)	Open access	In groups of five	Open access	In groups of five	Open access
T3. Experienced participants (EG1–EG5)	Open access	In groups of five	Open access	In groups of five	Open access
T4. Experienced participants (LEG1–LEG6)	Open access	In a single group of 15 participants	Open access	In a single group of 15 participants	Open access

Note: The label for the groups is listed in parentheses.

After the round is over, they receive the average earnings of the participants in their group.

We begin the experiment with a practice round in which we ask participants not to collect any tokens during the first 20 seconds of the 60-second practice round but to watch the screen carefully. This practice is designed to make certain that the participants observe the pattern of resource regrowth, and the dependency of future token growth on currently visible tokens. After this practice round, the first round is one of open access. Participants can harvest tokens from any location on their shared resource – the screen. Initially, 50 per cent of the environment cells are seeded with tokens. After the first round, we employ four different treatments (see Table 1).

The first treatment allows every participant open access to any location on the screen to which they move their avatar for all three rounds – without communication. This treatment and the data (as well other treatments not involving communication) are discussed in Janssen et al. (2008). We include this treatment as our baseline.

The second treatment provides participants who are participating for the first time in this experimental environment with the opportunity to discuss the experiment for 10 minutes between rounds 1 and 2, and again between rounds 2 and 3. They receive the following instructions: 'You can talk for 10 minutes about the experiment with your group members. You can discuss whatever you want as long as you do not threaten each other, and as long as there are no promises about side payments.' Each group is taken to a separate room. At this time, they know who the other four players are who share the same resource on the screen. One of the experimenters joins each of the three groups and quietly observes the discussion in the group.

The third treatment is the same as the second, but now it is populated with experienced participants. Participants are told that everybody has participated in a previous experiment using the same environment but without communication. They are also told that the experienced subjects shared different treatments, including open-access situations and an experimenter-designed form of private property (Janssen et al. 2008). Some participants involved in each of the groups of this third treatment had experienced the improved performance achieved in prior experiments under a private-property rule.[3]

The fourth treatment is the same as the third, with the difference that the full set of participants is brought together for a face-to-face discussion rather than in their own groups of five. Therefore, the identity of who is playing in which group is not revealed to the participants. In all of the designs except the first, two communication periods occur – after round 1 and after round 2. At the end of the experiment, participants complete a survey while the experimenters prepare the payments. We ask participants a short set of questions about their major (i.e., their primary field of study), gender, experience with video games, the number of hours they work during the school week, and the size of their high school.

The real-time spatial environment makes it difficult to calculate precisely the best strategy. A rule of thumb that would yield the highest payoffs for a group of individuals would be for each avatar to harvest two tokens per second without making big open spaces. This strategy would keep the average density of the tokens to 50 per cent, equally distributed in the environment. The resulting cooperative earning, including the five dollar show-up fee, would be in the range of $22 to $23 for each participant if all members of the group followed such a rule of thumb.

Results

We performed this series of experiments in the fall 2005 and spring 2006 semesters in the Interdisciplinary Experimental Laboratory at Indiana University. Seventeen groups of five participants were involved in the communication experiments, giving a total of 85 participants.[4] The average age of participants was 20 years. Half of the participants were female.

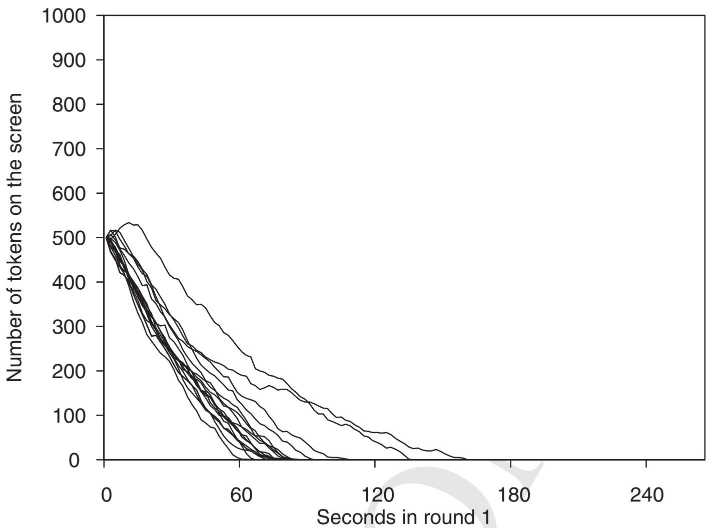

Figure 3. The number of tokens left in the renewable resource for the 17 groups during the first round of the experiment. The number was recorded every two seconds. The fat lines represent the groups composed of inexperienced participants

Round 1

All groups depleted the renewable resource rapidly in their first round, although there was some variation among experienced and inexperienced subjects (see Figure 3). On average, experienced participants took 111 seconds to harvest *all* of the tokens from the screen, leading to an average amount of 212 tokens collected per person. The inexperienced participants harvested all the tokens somewhat faster, in 75 seconds, with an average of 173 tokens collected. A one-way ANOVA test, $F(1,15) = 2.72$, $p = 0.12$, indicates, however, that inexperience did not lead to significantly faster depletion of the resource. Also, the number of tokens collected is not significantly different.

Compared with the rule-of-thumb behavior described above, this means that participants earned on average about one-fourth of the potential payments they could have earned. The participants had to watch the empty screen for the remaining time (up to the average of four minutes). We decided not to stop the round when the resource was depleted to provide the participants with a vivid experience of the lost opportunities that stemmed from overharvesting. Several groups depleted all the tokens in about 70 seconds and had to watch an empty screen for around three minutes. Thus, although experienced participants had earlier been through a three-round experiment in the same experimental environment, their behavior does not differ significantly from that of inexperienced subjects. We can therefore conclude that experience *alone* does not lead to significantly different behavior in the open-access situations.

Rounds 2 and 3

A previous set of noncommunication experiments involved 33 groups of 5 participants (Janssen et al. 2008). Experienced participants in the communication experiments, which are the focus of this article, were randomly drawn from the pool of participants in previous experiments. We will now discuss rounds 2 and 3 of the various communication treatments and highlight some remarkable results.[5]

In listening to the communication, we noticed that participants used attributes of the resource system for their coordination, which resulted from how we had built the experimental infrastructure. For example, participants discussed how to lay out the pixels on the screen so that they could allocate a unique subset to each of them and create a privately owned region. The participants engaged in a variety of clever mechanisms to allocate space. In some instances, they counted out so many dots on the screen and made a specific allocation to each and every person.

Communication with Inexperienced Participants

After round 1, participants generally discussed slowing down the speed of pressing keys, and therefore the speed of token collection. They also discussed spatial strategies regarding how to harvest tokens more effectively. One common topic was that they should not start harvesting immediately. They had seen in the practice round that the resource regenerated rapidly when they were not allowed to harvest for 20 seconds. They applied this lesson in discussing the strategies they should adopt. Spatial strategies varied from zigzag movement for enhancing replenishment to dividing the space into equal parts. The earnings of the groups in round 2 were increased compared to round 1, but participants still collected all the tokens *before* the end of the round and thus earned less than was feasible (Figure 4).

In the second communication round, participants confirmed with each other that they did better but wondered aloud how they could improve their returns (Figure 5). They also became more aware of the need to coordinate within the group. Two groups discussed stop-and-go strategies. For example, Group ‘IG4’ decided that when the resource was at

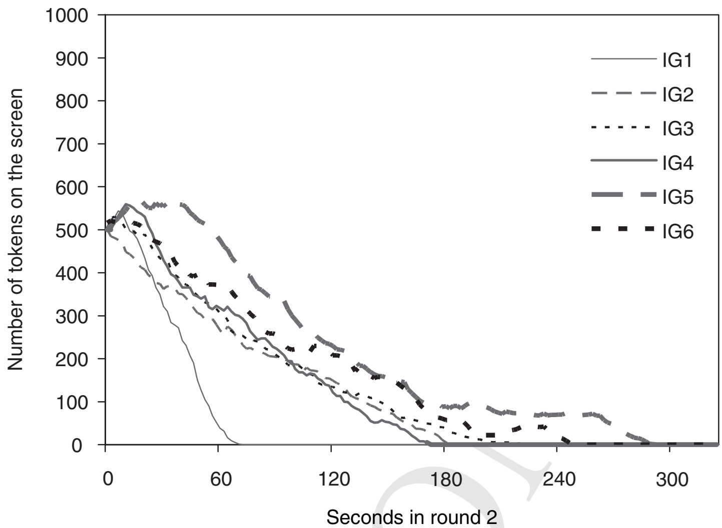

Figure 4. The number of tokens left in the renewable resource for the six groups of inexperienced participants during the second round of the experiment

risk of being depleted, participants should go down to the bottom of the screen in order to signal the need to stop harvesting. Soon thereafter, all avatars would be at the bottom of the screen signaling, and not harvesting for 10 seconds or so, letting the resource regrow. Group 'IG6' discussed the idea that they should harvest at a modest rate and 'try not to be an American'. Another group, 'IG3', included one person who announced he was not willing to cooperate despite the strong pressure of the other members of the group.

Communication with Experienced Participants in Five-person Groups

In each group, there were participants who had experienced private-property rules in the no-communication experiments we had conducted in the fall of 2005. That prior experience appears to have increased their performance (see Figures 6 and 7). In group discussions, they lamented that they could do much better if they could only cooperate, for example by splitting up the resource.[6] They also discussed waiting at the beginning of the game to increase the number of tokens on the screen. This is clearly shown by the increase in the total tokens on the screen of groups EG2, EG3, and EG4 (Figure 6). The other two groups did not wait, but had a

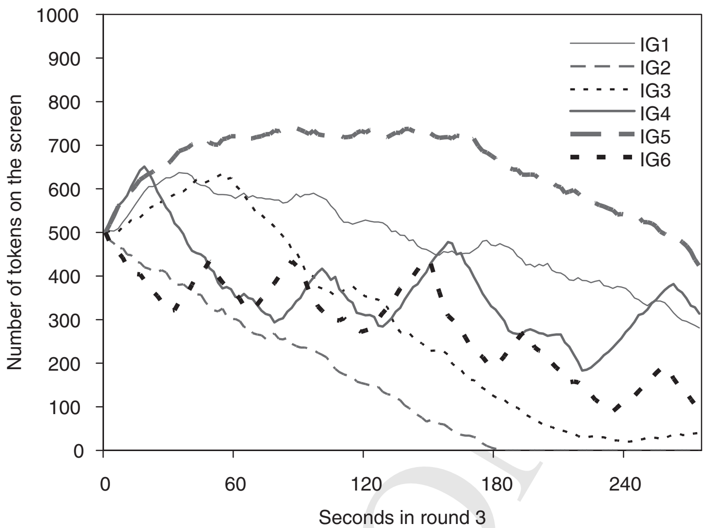

Figure 5. The number of tokens left in the renewable resource for the six groups of inexperienced participants during the third round of the experiment

modest initial harvesting rate. After the second discussion period, groups were often rather satisfied and did not have as much to discuss with each other, other than to confirm a continuance of their previously agreed-upon strategy. Three groups waited to start harvesting and only one group depleted the resource before the experiment ended (see Figure 7).

Communication within Large Groups of Experienced Participants

Again, in each group of 15 participants, some had previously experienced the private-property regime, which they then discussed with each other. They also shared the experience of viewing the remarkable regeneration of the resource in the practice round when they were not allowed to harvest for 20 seconds (see Figures 8 and 9).

The most amazing use of the attributes of the experimental environment itself occurred in one of the sessions where the three groups were all brought together to form one big discussion group (LEG1, LEG2, and LEG3 in Figures 8 and 9). The participants used two attributes of the resource – the computers and screens that we had programmed for the open-access experiment. One related to the small clock that we had put in the upper, left-hand corner of the screen so that they could monitor the

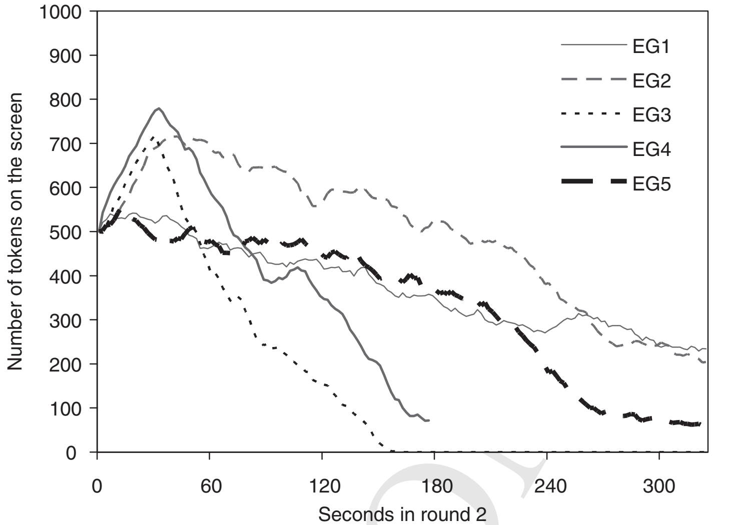

Figure 6. The number of tokens left in the renewable resource for the five groups of experienced participants during the second round of the experiment. Due to a technical glitch, the data on tokens left in the resource was not recorded in our database after three minutes for experiment EG4. This had no impact on the experiment itself, as subjects could see the screen and payoff information was complete.

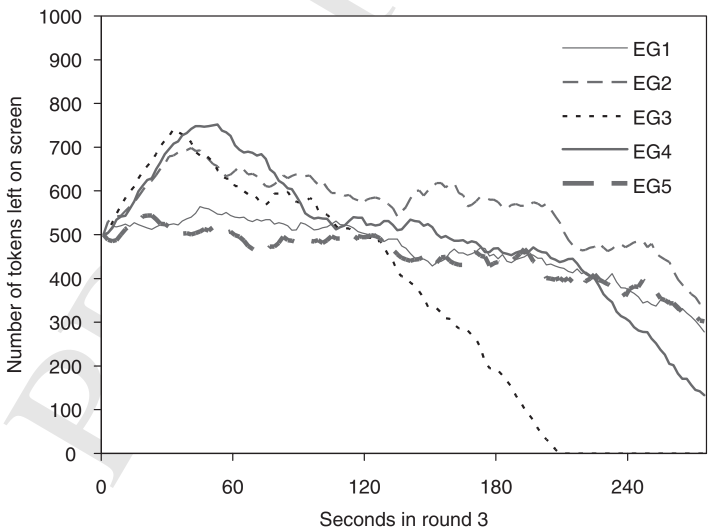

Figure 7. The number of tokens left in the renewable resource for the five groups of experienced participants during the third round of the experiment

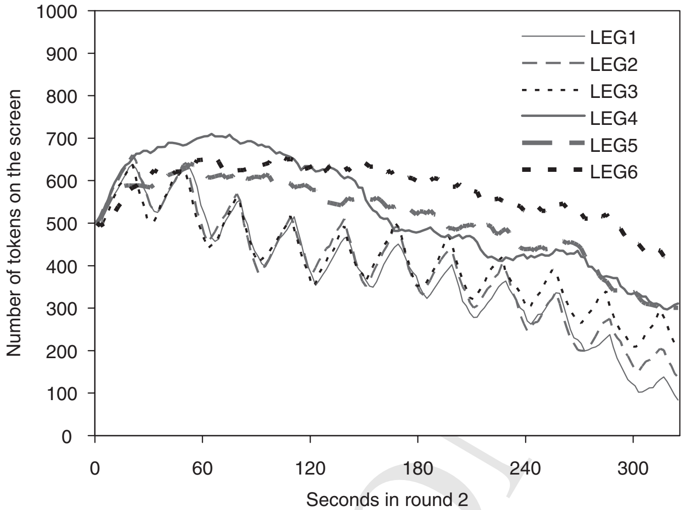

Figure 8. The number of tokens left in the renewable resource for the six groups of experienced participants whose communication occurred in a large group of 15 participants that combined all three groups who shared a single resource during the second round of the experiment

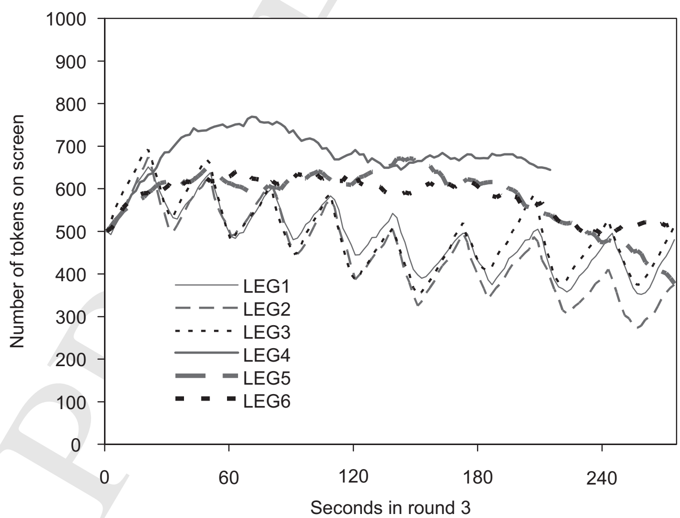

Figure 9. The number of tokens left in the renewable resource for the six groups of experienced participants whose communication occurred in a large group – combining all three groups – during the third round of the experiment. For group LEG4, the data on tokens in the resource left were not recorded at the end of the round due to a computer glitch.

amount of time that had elapsed. The other was the sound that pressing the arrow keys to 'harvest' a resource unit makes when you have to move your cursor over a spot in order to harvest it. When a large group of 15 people are all harvesting at the same time, they make very audible sounds of pressing keys.

The group decided that they would wait 20 seconds and not harvest at all so that regrowth started. (This reflected their experience in the practice round, when we had asked them to refrain for 20 seconds and watch the system regenerate.) They then agreed to harvest for 10 seconds and then refrain again for the next 20 seconds. They thus developed a unique temporal rotation system so that the resource could regenerate and they could continue to harvest over time. Since the clock located on their screen was the same on every terminal screen, and since silence prevailed if no one harvested, but you could hear the pressing of a key if someone broke the agreement, they were able to monitor each other's behavior and to use the particular aspects of this physical environment to great advantage. They also discussed what they should do if someone continued to press on a key to harvest in the agreed-upon 'no-harvest' 20-second segments. One participant suggested that if they noticed folks breaking this agreement, they should *all* start harvesting immediately. This is the equivalent of the 'grim trigger' strategy proposed by game theorists for a method that participants in a dilemma situation could themselves use to threaten anyone who broke agreements.

When we designed the experiment, none of these attributes were considered to be relevant for the participants when they made decisions about rules. They were just aspects of the screen and program that we designed in order to run the experiment. The participants figured out a fascinating rule that they could easily monitor and follow using those attributes. This was a big surprise to us all when it occurred, but made us think about how harvesters in field settings do use local attributes of their resources if and when they make their own rules.

In the other experiment where all 15 participants had one discussion group, the participants decided first to wait to let the resource replenish and then to split up each of the three resources in equal parts.

General Observations

When we compare the four treatments of our current experiments (T1–T4), we see that the subjects who had experienced our earlier experiments (E) made decisions that were similar to those of inexperienced subjects (I) in the first round without communication. Once they could communicate, however, past experience gave them an advantage (see Tables 2 and 3). An explanation for this is that participants with experience have had vivid

Table 2. Average tokens collected per second per group for different experimental treatments

	Round 1	*Round 2*	*Round 3*
Current experiments:			
T1 Open access (I)	3.50 (0.45)	2.80 (0.49)	3.20 (0.47)
T2 Group discussion (I)	3.20 (0.16) [0.17]	4.20 (0.72) [<0.01]	6.80 (1.12) [<0.01]
T3 Group discussion (E)	3.43 (0.50) [0.84]	6.23 (1.60) [<0.01]	7.96 (1.11) [<0.01]
T4 Three-group discussion (E)	4.33 (1.96) [0.44]	7.71 (0.51) [<0.01]	7.66 (0.42) [<0.01]
Previous experiments with property rights:			
T5 Private property in round 2 (chosen)	3.30 (0.19) [0.28]	4.21 (0.96) [0.02]	3.58 (0.52) [0.25]
T6 Private property in round 2 (imposed)	3.20 (0.38) [0.24]	4.39 (1.35) [0.05]	3.34 (0.36) [0.57]

Note: The numbers in parentheses are the standard deviations. The numbers in brackets are the *p*-values of the one-sided ANOVA test between the open-access condition and the treatment of that row.

Table 3. *P* statistics of the one-sided ANOVA test on differences in the tokens collected per group for different experimental treatments in round 2

	T3 Group discussion (E)	*T4 Three-group discussion (E)*	*T5 Private property in round 2 (chosen)*	*T6 Private property in round 2 (imposed)*
T2 Group discussion (I)	0.02	< 0.01	0.98	0.77
T3 Group discussion (E)		0.06	0.01	0.04
T4 Three-group discussion (E)			< 0.01	< 0.01
T5 Private property in round 2 (chosen)				0.76

experiences with prior successes and failures and more concrete examples of what might or might not work. They often designed rules to allocate turf that resembled those of the earlier private-property experiments (and were broadly similar to rules used in field settings). The inexperienced participants were somewhat more creative and explored different types of arrangements, which were not always successful.

We analyzed the effects of different treatments on the number of tokens the group collected in rounds 2 and 3 (see Tables 2 and 3). The groups do not differ significantly from each other in round 1. Thus, experience alone did not result in better performance. In rounds 2 and 3, the number of tokens collected is significantly higher in all treatments compared to the default case of open access (Table 2). The number of tokens collected in round 2 differs between treatments 2, 3, and 4 (Table 3). In treatments with experienced participants, significantly higher amounts of tokens were collected compared to the groups with inexperienced participants. This indicates that the experience of participants in earlier experiments led the participants to derive informal arrangements that resulted in higher token collections. When three groups were able to communicate together about the informal arrangements they might use, performance also increased. This is interesting, since the 15 participants brought together in one group do not know the identity of the other participants in their smaller groups. This indicates that knowledge exchange leads to better performance, but not necessarily knowledge of the identity of other participants. In round 3 of the experiments, the number of tokens collected does not differ between the three communication designs (p-values for all one-sided ANOVA tests were above 0.1).

It is important to note that the earlier designs of chosen (T5) or imposed (T6) property-rights systems in round 2, as discussed in Janssen et al. (2008), led to an average of around four tokens per second, which is significantly higher than the open-access situation without communication (Table 2). It is a similar level, however, to that of open access with one session of communication by inexperienced participants (Table 3). With more communication or more experience, the subjects are able to retrieve significantly higher resource-use levels in these open-access situations.

We finally discuss the spatial and temporal strategies the groups came up with after communication, and how they differ for the different treatments. For each participant, we look at where they collected the tokens and how this differs among the treatments. A spatial concentration index is constructed that quantifies how spatially concentrated the participants are in collecting their resources. Do they collect all over the screen, or do they collect only in a well-defined area? We calculate the index by splitting up the resource into five columns of ten cells wide and twenty cells high. We calculate how much each participant collected in the five parts of the resource. Then, we calculate the index by determining which agent dominated which column, adding up the tokens collected by the agents in the columns they dominated and dividing this by the total number of tokens collected. For example, when participants agree to split up the resource in five equal parts and collect tokens only on their own turf, we will see that each agent dominates one part of the resource. If they keep collecting only in their own turf, the spatial concentration index is 1.0, which means that in each turf only one participant collected tokens. When participants collect tokens randomly, each participant will collect tokens in all turfs. In that case, the spatial concentration index is equal to 0.2, which means that tokens are collected *evenly* from the whole resource. Thus, the spatial concentration index varies between 0.2 and 1.0.

The spatial concentration index is on average 0.37 in round 1 across all experiments. When participants communicated, we start to see a different pattern in round 2 (see Figure 10). For experienced and inexperienced groups who communicated at the group level, we see a positive correlation between the spatial concentration and the number of tokens collected by the group in round 2. This indicates that groups who successfully decided to allocate turfs have higher levels of spatial concentration of harvesting and are more successful in maintaining the resource size at high levels. We also see that the inexperienced groups were much less successful in this than the experienced groups. One of these larger groups of 15 participants, as discussed above, agreed to wait 20 seconds, and then harvest for 10 seconds, etc. They therefore had no spatially explicit strategy. In sum, Figure 10 indicates that most groups increased their performance by defining their turfs.

After the second session of communication, we observe an interesting difference between experienced and inexperienced groups. Four of the inexperienced groups (IG1, IG3, IG4, and IG6) do not fit the relation of increasing spatial concentration of harvesting and better performance. After the first session of communication, the inexperienced groups were not very effective, but in the second session of communication they made more explicit agreements on strategies to harvest the common resource. IG4 decided to split up the resource in five equal parts, vertically. When we corrected the spatial concentration index for this, we see that this observation fits the general trend. Groups IG3 and

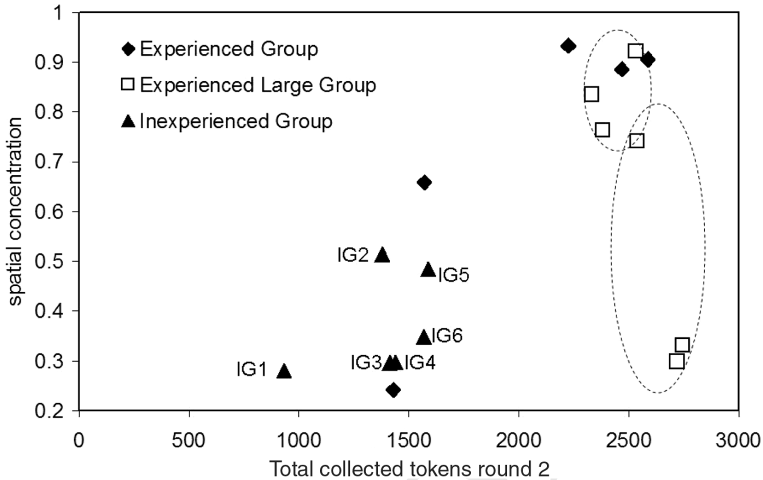

Figure 10. Spatial concentration index versus total collected tokens by groups in round 2 for three different treatments. IG1-IG6 indicate six inexperienced groups. The circles indicate which three groups were together in the communication experiment with three groups.

IG6 decided to focus on speed, not on space. Group IG1 consisted of four cooperative participants and one participant who was outspokenly defective and who harvested more than twice the levels of the cooperative members of the group.

Figure 11 indicates that groups who had experience with private-property regimes start to mimic this type of institutional solution for sharing the common resource in their discussions. Four of the inexperienced groups focused on turfs, although space was also used twice. Hence, there was more institutional innovation among the inexperienced participants.

Conclusions

A real-time and spatially explicit renewable resource experiment was used to study the effects of communication on institutional innovation in a commons dilemma. This new experimental environment provides more opportunities for choice than the 20 to 30 decisions made in relation to harvesting level in previously undertaken commons experiments.

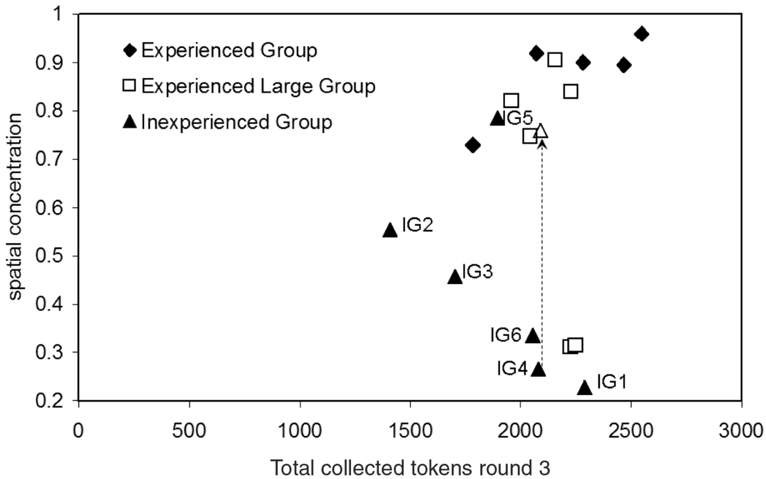

Figure 11. Spatial concentration index versus total collected tokens by groups in round 3 for three different treatments. IG1-IG6 indicate six inexperienced groups. Since in group IG4 the participants decided to split up the resource horizontally, the spatial concentration is low in the original formulation. If we take into account that the resource was split up horizontally IG4 instead of vertically, we get a higher spatial concentration for IG4, which is indicated in the figure by an arrow and an empty triangle.

The participants have to decide where to harvest and how rapidly to harvest, and are constrained by the spatial nature of their virtual world.

In line with previous experiments, we find that enabling participants to engage in face-to-face communication leads to a significant improvement in the performance of the groups in open-access situations. Although experienced subjects reached a higher level of earnings after one session of communication, inexperienced subjects caught up quickly after the second session of communication. Groups of inexperienced subjects do as well as or even better than groups of subjects who had already experienced the experimenter-designed private-property regimes (Janssen et al. 2008).

Shankar and Pavitt (2002) argue that voicing of commitments and development of group identity and norms constitute the main explanation for the better performance of communication experiments. This is only partly supported by our results. When experienced participants communicated on a face-face-basis without knowing who was in their group, their performance was equally as good as that of groups of similarly experienced participants who communicated in five-person groups and thus knew who was in their group (Figure 10). Furthermore, we also observed that inexperienced participants needed an extra session of communication to reach the same level of performance, although there was no significant difference in their results in round 1. This suggests that exchanging insights on what are good strategies during communication is an important way for groups to increase performance. Due to the more complicated experimental environment, exchange of insights might play a larger role than Shankar and Pavitt (2002) posited.[7]

Experienced participants tend to recommend adoption of previously experienced property rules that had led to an increase in their payoffs in a previous experiment. The participants exchanged their understanding of the earlier experiment and rapidly agreed on a voluntary split of the resource in equal parts similar to a private-property rule. Initially, the inexperienced groups were not successful in developing an effective strategy for the second round of the experiment. In round 3, the groups used jointly agreed-upon strategies as effectively as the experienced groups, although more variability existed in the strategies used.

This study relies on undergraduate students as paid participants.[8] Given the abstract nature of the experiment, we do not intend to derive conclusions for actual resource management. We do find it striking, however, that participants without experience in natural resource management design spatial allocation strategies similar to those found so frequently in the field. Spatial allocation of the resource was the main strategy used by more than two-thirds of the groups to solve the collective-action problem. In the other cases, strategies based on timing of when and how fast to harvest were used.

Thus, we can begin to address the three key questions on governance of common-pool resources posed in the introduction. With our new dynamic, experimental environment, we start to develop methods that record the initial process of self-organization (question 1). The informal rules that were developed focused on the coordination of space and time instead of maximum harvest levels. In a complex environment such as this, coordination of space and time is easier to self-monitor than an effort to impose quantity restrictions (question 2). Face-to-face communication seems to be powerful, as it enables participants to share insights about potential joint strategies and reduces the uncertainty about the actions of others in the group (question 3).

To conclude, we are particularly pleased with the opportunities that developing the software facilities for utilizing a real-time, dynamic, spatial commons has provided for conducting experimental research into how those facing a commons dilemma craft their own agreements for reducing overharvesting. We are beginning to sort out the relative importance of having experienced similar situations with different rules that potentially enable participants to learn more rapidly how to improve performance when they face a similar situation. We also see that communication facilitates innovation and can sometimes outperform learning from prior experience. Communication, however, can also lead to worse outcomes. We plan to extend our use of this dynamic, spatial, experimental environment to study the processes involved in voluntary sanctioning among participants in a commons dilemma.

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NOTES

1. For repeated CPR games without communication, Ostrom et al. (1994) found that subjects tended to withdraw more than the Nash equilibrium in the first rounds and approach the Nash from below. With face-to-face communication, subjects tended to do better than the Nash equilibrium.
2. The instructions for the experiment and the survey can be received upon request from the first author.
3. In this private-property rule, participants can collect tokens without legal restrictions within their spatially defined turf. If a participant harvests a token outside of their spatially defined property, there is a probability of 10 per cent for each illegally harvested token that the participant will be caught. If caught, the avatar for the participant blinks red for a few seconds, and a penalty is subtracted from the earnings of the participant.

4. In a previous set of non-communication experiments where different property rules were enabled, we had 33 groups of 5 participants.
5. Movies of the experiments, which show the state of the resource and the location of the avatars over time, can be found at http://www.public.asu.edu/~majansse/dor/nsfhsd.htm.
6. One participant mentioned that he met a fellow student sometime after they had both been in our earlier experiments. They compared notes on what had happened and how much they had earned. The student told the others in his group that he had found out that the participant in an experiment where space was allocated to each participant had earned twice as much as he had earned in the prior experiment. Thus, he urged others to agree to a division of space on the computer screen.
7. In the prior CPR experiments with a relatively complex quadratic payoff function, subjects also spent time in the early rounds of communication exchanging insights about which strategies would generate the optimal level of payoffs for the group (Ostrom et al. 1994).
8. While some experimentalists have criticized using undergraduate students as experimental subjects (see, for example, Levitt and List 2007), a current study by Ahn et al. (2008) compares results in experiments involving doctoral and PhD students coming from 41 countries. The results are very similar to the results found in the lab when undergraduate students were the subjects.

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