W07-8 5/10/07

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 between 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 a similar private property type of experiments, 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.

1. Introduction

The existence and continuity of many self-organized, common-property regimes is 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. One question relates to the initial process of self-organization. Few researchers are able to witness the discussions that first 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 social dilemma (that may then help to solve the first-level social dilemma of regulating the CPR). How do they arrive at a solution?

A second question relates to why self-organized fisheries tend not to limit harvesting to a specific quantity of fish. Allocating quantities of resource units is frequently used by terrestrial common-property regimes (Schlager 1994). Since Individual Transferable Quota (ITQs), are recommended as an optimal allocation device for fisheries (Baumol and Oates 1988; Anderson 1995), this is particularly a 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 much higher joint outcomes (Ostrom and Walker 1991). Let us turn to the third question first since experimental research has helped researchers to understand the first question somewhat better, and the experiment discussed in this paper helps to answer the second and first questions.

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, Gardner, and Walker 1994). In experimental settings, simply allowing communication has repeatedly been shown to improve outcomes (Sally 1995). 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, Friedman, and Gjerstad forthcoming; Ostrom 1998; Ostrom, Gardner, and Walker 1994; Fehr and Gächter 2000). 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 social dilemma experiments, initial behavior tends to be more cooperative than predicted (Isaac, McCue, and Plott 1985; Orbell and Dawes 1991; Goetze and Orbell 1988). Without communication, however, initial levels of cooperation tend to decline rapidly (Davis and Holt 1993; Isaac, Walker, and Thomas 1984). Face-to-face communication reverses this downward cascade (Cardenas, Ahn, and Ostrom 2004; Hackett, Schlager, and Walker 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, Johnson, and Croson 2006). In some experiments, 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 quadratic harvesting equation originally posited by Gordon (1954) has been used for the payoff function, subjects did spend time initially to be sure they understood how much harvest was 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 voicing of commitments and 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 together a good strategy as well as building commitments so as to achieve far better outcomes than achieved in repetitive situations without communication.

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 (Shivakoti and Ostrom 2001; Gibson, McKean, and Ostrom 2000; Netting 1981; McCarthy 2004). 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 very 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, Edwards-Jones, and Kaiser (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.
>
> . . . 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: 124–25)

In contrast to these territorial allocations, many scholars have advocated that 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 dominate use of TURFs, rather that 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 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.

In this paper, participants share a common renewable resource that is spatially explicit. We allow the participants to communicate on informal arrangements to improve their performance in harvesting the resource. We will see that face-to-face communication is effective in solving collective action problems, and that the types of informal rules participants come up with are largely based on the spatial allocation of territories for individual use of the resource.

2. A Virtual, Dynamic Spatial Experiment

The experimental environment we have designed to use in this study is much richer in terms of the possible 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 and 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 have found methods to allocate either space or time to one another so that they do not overharvest the resource and face an empty screen.

Due to the richness of the experimental environment, it is suitable to study how subjects innovate rules in a complex environment where they cannot make an estimate of the total quantity of resource units available but can see resource renewal patterns and craft innovative rules for allocating space and time to one another as they way of using the common resource. In our current experiments we thus examine institutional innovation in a virtual 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 and to our surprise, knowing who the other participants 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 others' 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, 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, are immense in their variety (see Digital Library of the Commons, http://dlc.dlib.indiana.edu/).

2.1. Experimental Design

The experiment[2] is designed to test the effect of communication on the decisions of participants in a real-time spatially explicit commons. As discussed in the previous section, we know that cheap talk increases cooperation. We were especially interested in the type of strategies they developed and whether experience in earlier experiments enabled individual participants to learn and how it affected their discussions and decisions.

In the experiment, groups of five participants share a renewable resource that grows on a 20 X 50 spatial grid of cells. They can collect tokens during three rounds each of which is approximately five 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 collect as many tokens as they can, quickly there will be no tokens remaining on the screen. Once every token has been harvested, no further opportunity exists for any new tokens to be created.

(Figures 1 and 2 about here)

We began 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. This practice was designed to make certain that the participants can observe the resource re-growth, and the dependency of future token growth on currently visible tokens. After this practice round, the first round is of open access. Participants can harvest tokens from any location on their shared resource—the screen. Initially, 50 percent of the environment cells are seeded with tokens. After the first round, we employed four different treatments (see Table 1).

(Table 1 about here)

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 data (as well other treatments not involving communication) is discussed in Janssen et al. (2006). We include this treatment as our baseline.

The second treatment provides participants, who are participating for the first time in this experimental environment, the opportunity to discuss the experiment for ten 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 now 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, however, with experienced participants. These participants have participated in a previous similar experiment without communication in which they experienced different treatments, including open-access situations and an experimenter-designed form of a private property. Some participants involved in each group of this third treatment, had experienced the improved performance they had achieved in prior experiments under the private property rule. 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 percent for each illegally harvested token that the participant is 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.

The fourth treatment is the same as the third treatment with the difference that the participants have a discussion among the full set of 15 participants 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 2 and after round 3. At the end of the experiment, participants complete a survey while the experimenters prepare the payments. We asked participants a short set of questions about their major, 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 percent 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.

2.2. Results

We performed a series of experiments in the fall 2005 and spring 2006 semesters in the Interdisciplinary Experimental Laboratory at Indiana University. Seventeen groups of five participants each were involved in the communication experiments, for a total of 85 participants.[3] The average age of participants was 20 years. Half of the participants were female.

2.2.1. Round 1

Figure 3 illustrates that all groups depleted the renewable resource rapidly in every first round, although there was some variation among experience and inexperienced subjects. On average, it took the experienced participants 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, 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 experience did not lead to significantly faster depletion of the resource. Also the number of tokens collected is not significantly different.

(Figure 3 about here)

Compared with the rule of thumb behavior described above, this means that participants earned on average only 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 a vivid experience in the lost opportunities that stemmed from overharvesting. Several groups depleted all tokens in about 70 seconds and had to watch an empty screen up to an average of four 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 new inexperienced subjects. We can therefore conclude that experience alone does not lead to significantly different behavior in the open-access situations.

2.2.2. Rounds 2 and 3

In a previous set of noncommunication experiments, we had 33 groups of 5 participants (Janssen et al. 2006). Experienced participants in the communication experiments, which are the focus of this paper, had participated in these earlier experiments. We will now discuss rounds 2 and 3 of the various communication treatments.[4] Although we will not discuss each group in detail, we will highlight some remarkable results.

What we found was somewhat startling in listening to the communication patterns among the participants in the communication experiments was their effort to search out attributes of the resource system that they were facing that 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.

2.2.3. Communication with Inexperienced Participants

After round 1, participants generally discuss slowing down the speed of clicking, and therefore the speed of token collection. They also discuss 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. 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, the 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 risked to be depleted, participants should go down to the bottom of the screen, in order to signal the need to stop harvesting. Pretty soon thereafter, all avatars would be at the bottom of the screen signaling, and not harvesting for 10 seconds or so, letting the resource re-grow. Group ‘IG6’ discussed 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.

(Figures 4 and 5 about here)

2.2.4. 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.[5] They also discussed waiting in the beginning of the game to increase the number of tokens on the screen. This is clearly shown by the increase of the total tokens on the screen of groups EG2, EG3, and EG4 (Figure 6). The other two groups did not wait, but had a modest initial harvesting rate. After the second discussion period, groups were often rather satisfied and had not much to discuss other than to confirm a continuance of their previously agreed upon strategy. Figure 7 shows that again three groups waited to start harvesting and only one group depleted the resource before the experiment ended.

(Figures 6 and 7 about here)

2.2.5. Communication within Large Groups of Experienced Participants

Again, in each group of 15 participants, some of them had experienced the benefit of private property and they also shared the experience of viewing remarkable regeneration of the resource in the practice round when they were not allowed to harvest for 20 seconds (see Figures 8 and 9).

(Figures 8 and 9 about here)

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 (LEG 1,2 and 3 in Figures 8 and 9). The participants used two attributes of the resource—the computers and screens that we had assigned to them as programmed for the open-access experiment. One related to the small clock that we had put up in the upper, left-hand corner of the screen so that they could monitor the amount of time that had elapsed. The other was the sound that clicking 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 clicking sounds.

The group decided that they would wait 20 seconds and not harvest at all so that re-growth started. (This reflected their experience in the pretest round where 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 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 click 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 click in the no-harvest 20-second segments. One participant suggested that if they noticed folks breaking this agreement that 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 do make their own rules.

The other experiment where all 15 participants discussed with each other decided first to wait to let the resource replenish and then to split up the resource in equal parts.

2.2.6. General Observations

When we compare the four different treatments we see that the experience of an earlier experiment affected performance in the communication experiments (see Figure 10). An explanation for this is that participants with experience have had a vivid experience with successes and failures in the past and more concrete examples what might work or not. They often designed rules to allocate turf that resemble the private property experiments (and 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.

(Figure 10 about here)

We analyzed the effects of different treatments as well as characteristics of the groups on the number of tokens the group collected in rounds 2 and 3 (see Table 2). We find the tokens collected in round 2, scaled to tokens per second of the experiment, correlates significantly with experience and the three-group communication. This indicates that experience of participants in earlier experiments, which did not affect the tokens collected in round 1, lead the participants to derive informal arrangements that resulted in higher token collections. Interestingly, when three groups are able to communicate together about the informal arrangements they could consider using, 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 groups. This indicates that knowledge exchange leads to better performance, but not necessarily knowledge of the identity of other participants.

(Table 2 about here)

Looking at the tokens collected in round 3, we found that round-2 performance is a good predictor for round 3. Further, a higher share of males in a group lead to a decline in the number of tokens collected in round 3. This is consistent with the general finding in lab experiments that male participants behave in a more selfish fashion than female participants (Chermak and Krause 2002). In our analysis, we do not find a significant relation between tokens collected and the year of the college program the students are in, nor their major.

It is interesting to note that imposed or chosen property right systems as discussed in Janssen et al. (2006) led to an average of around four tokens per second, which is significantly higher than the open-access situation without communication. It is a similar level, however, to that of open access with one round of communication by inexperienced participants (Table 3, Round 2, Row 2). With more communication or more experience the subjects are able to retrieve significant higher resource-use levels in these open-access situations.

(Table 3 about here)

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 where they collected the tokens and how this differs among the treatments. We do this by splitting up the resource into five columns of ten cells wide and twenty cells long. We calculate how much each participant collected in the five parts of the resource. Then we calculate a so-called spatial concentration index by determining which agent dominated which column, adding up the tokens collected by the agents in these 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 all tokens are collected by a participant from one part of the resource. When participants collect tokens randomly, they will harvest equal amounts at each part of the resources. 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 is between 0.2 and 1.0.

The spatial concentration index is on average 0.37 in round 1. We do not see a difference between the treatments. When participants communicated we start to see a different pattern in round 2 (see Figure 11). For experienced and inexperienced groups who communicated at the group level, we see 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. An interesting, odd position is for the two treatments that brought all three groups together for the communication rounds. One of these larger groups of 15 participants, as discussed above, agreed to wait 20 seconds, and then harvest for 10 seconds, etc. They had therefore no spatially explicit strategy. In sum, Figure 11 indicates that most groups increased their performance by defining their turfs.

(Figure 11 about here)

After the second round 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 round of communication, the inexperienced groups were not very effective, but in the second round 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 IG4 and IG6 decided to focus on speed, not on space. Group IG1 consisted of four cooperative participants and one participant who was outspoken to be defective and who harvested more than twice the levels of the cooperative members of the group.

Figure 12 indicates that groups that 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.

(Figure 12 about here)

3. 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 environment. This experimental environment provides many more opportunities for choice than deciding on the level of harvest as is the case in previously undertaken commons experiments. The participants have to decide where to harvest, how rapidly to harvest, and are constrained by the spatial nature of their virtual world.

In line with previous experiments, we find that communication alone leads to a significant improvement of the performance of the groups in open-access situations. Although experienced subjects reached a higher level of earnings after one round of communication, the inexperienced subjects caught up quickly after the second round of communication. It is remarkable that the groups do as well or even better than those who earlier had been in the experimenter-designed private-property regimes (Janssen et al. 2006). Shankar and Pavitt (2002) argue that voicing of commitments and development of group identity and norms is the main explanation of the better performance of communication experiments. This is only partly supported by our results. When participants could communicate on a face-face-basis, but did not know who was in their group, the performance was equally good as groups of similarly experienced participants (Figure 10). Furthermore, we also observe that inexperienced participants needed an extra round of communication to reach the same level of performance, although there was no significant difference of their experience 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) indicated.

Experienced participants mainly mimic previously experienced effective rules, the property right rule of the previous experiment. The participants exchange their understanding of the previous experiment and rapidly agree on a voluntary split of the resource in equal parts similar to private property rule. The inexperienced groups were initially not successful in developing an effective strategy for the second round of the experiment. In round 3, the groups used strategies as effectively as the experienced groups, although there was much more variability in the strategies used.

In field studies, the spatial allocation of the resource has been a frequently used strategy. We found that in more than two-thirds of the groups, spatial allocation of the resource was the main strategy to solve the collective-action problem. In the other cases, strategies based on timing when and how fast to harvest were used.

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 on how those facing a commons dilemma craft their own agreements for reducing overharvesting. We are beginning to sort out the relative importance of experiencing 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 conditions that are conducive to voluntarily using sanctions and the processes involved in voluntary sanctioning among participants in a commons dilemma.

Acknowledgments

An earlier version of this paper was presented at the 26th Annual Meeting of the Association for Politics and the Life Sciences (APLS), Indiana University, Bloomington, October 25-26, 2006. We appreciate the support of the National Science Foundation for the grant ‘Dynamics of Rules in Commons Dilemmas.’ Many people have been involved in this research. Janssen, Robert Goldstone, Filippo Menczer, and Ostrom designed the original experiment. Yajing Wang and Muzaffer Ozakca changed the original forager software of Robert Goldstone into the software we use for the experiments. Rachel

Vilensky recruited the participants. Yajing Wang, Michael Schoon, Tun Myint, Pamela Jagger, Marty Anderies, David Schwab, and Frank van Laerhoven assisted Janssen and Ostrom in performing the experiments. Also, many graduate students, staff, and faculty pre-tested the experiments and we thank them for all of their help.

NOTES

[1] For repeated CPR games without communication, subjects do tend to withdraw more than the Nash equilibrium in the first rounds and approach the Nash from below. With face-to-face communication, subjects tend 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 a previous set of noncommunication experiments, we had 33 groups of 5 participants.

[4] Movies can be found of the experiments, which show the state of the resource and the location of the avatars over time, at http://www.public.asu.edu/~majansse/dor/nsfhsd.htm

[5] 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.

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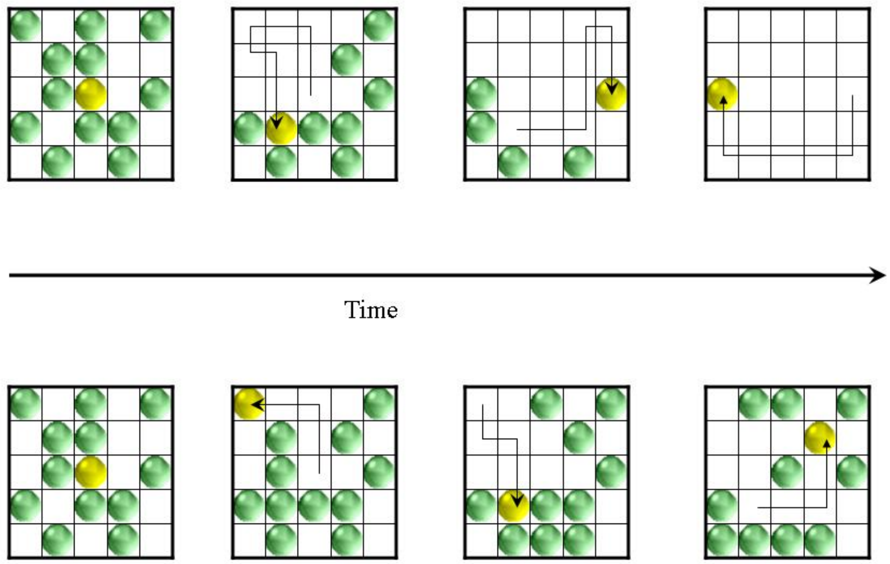

Figure 1. Four snapshots of two harvesting strategies by two different types of participants in a hypothetical situation of a 5x5 resource. On the top row in the figure above, the participant moves its avatar eight steps per time period. There is almost no time for regeneration, and a participant following this strategy overharvests the resource by the fourth snapshot. On the bottom row, the participant moves its 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, where the green tokens are the potentially regenerating resource units, black cells are empty cells, and the yellow dot is the agent's avatar. Blue dots are the locations of the four other agents.

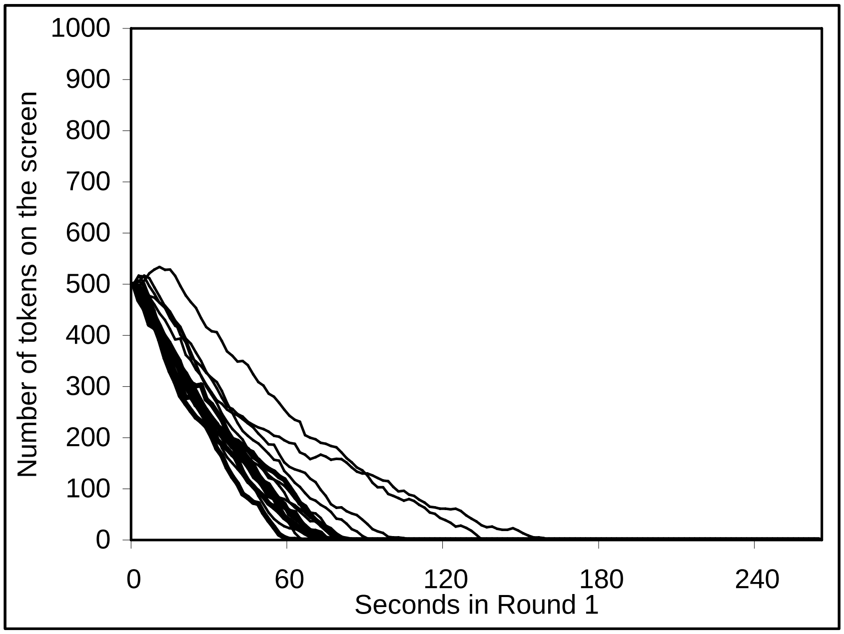

Figure 3. The number of tokens left in the renewable resource for the 17 groups during the first round of the experiment. The number was recorded every two seconds. The fat lines represent the groups with inexperience participants.

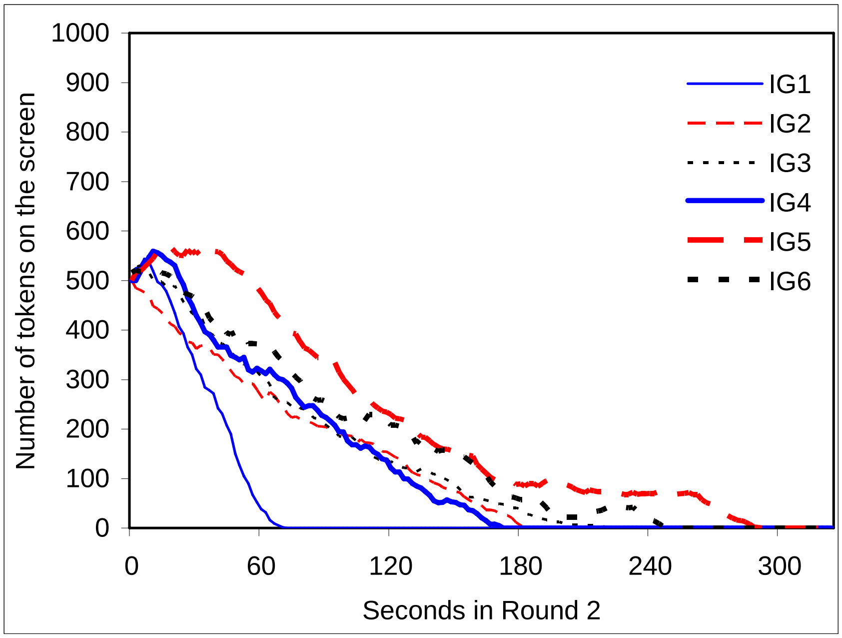

Figure 4. The number of tokens left in the renewable resource for the six groups of inexperienced participants during the second round of the experiment.

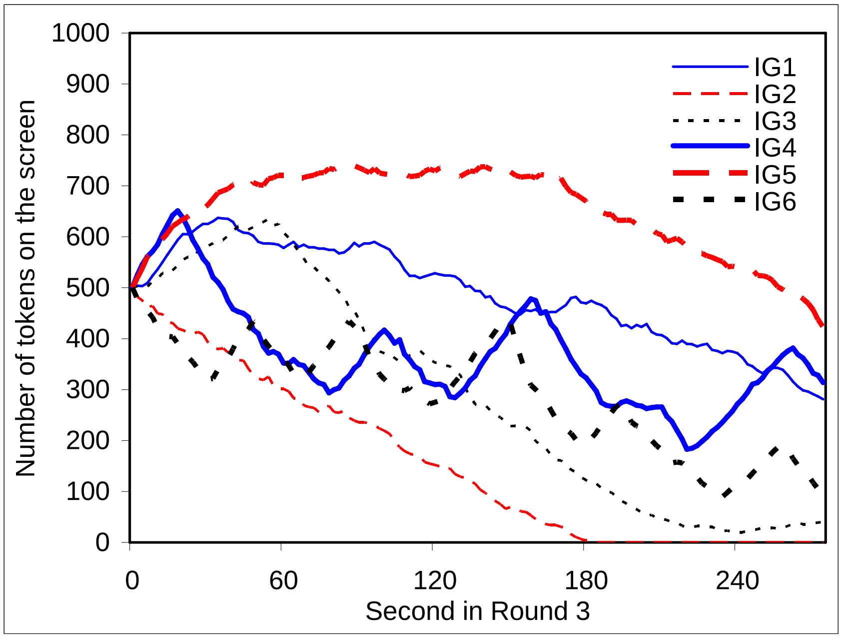

Figure 5. The number of tokens left in the renewable resource for the six groups of inexperienced participants during the third round of the experiment.

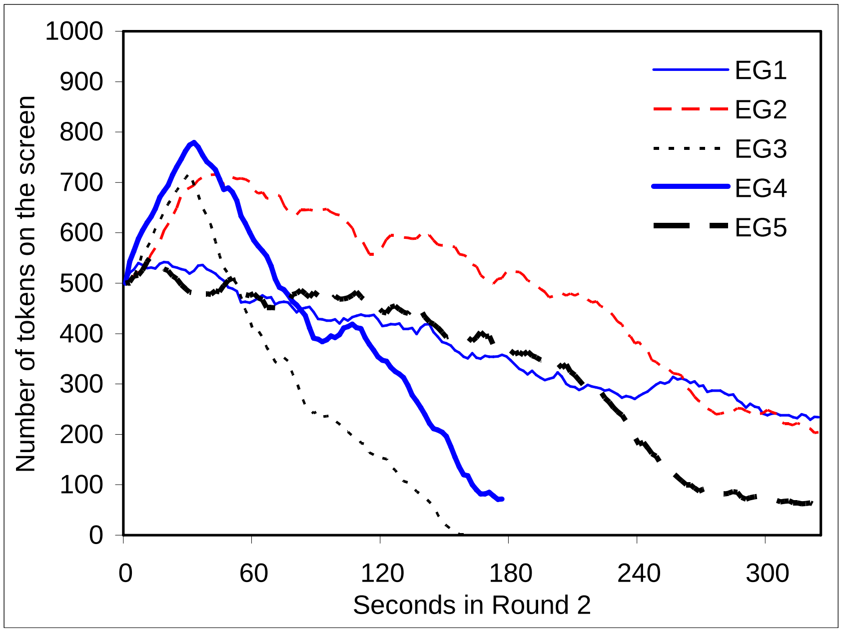

Figure 6. The number of tokens left in the renewable resource for the five groups of experienced participants during the second round of the experiment. For experiment EG4, the data on tokens in the resource left were not recorded till the end of the round.

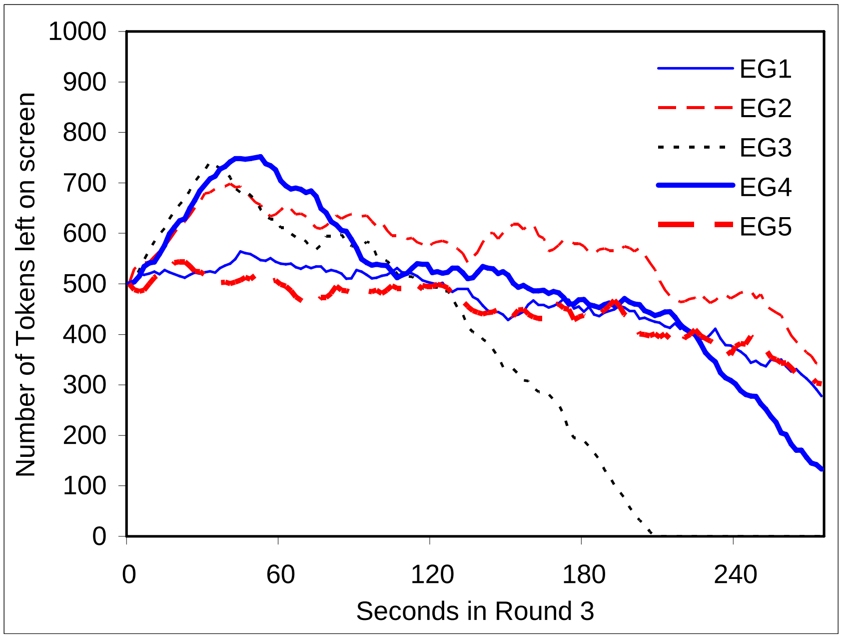

Figure 7. The number of tokens left in the renewable resource for the five groups of experienced participants during the third round of the experiment.

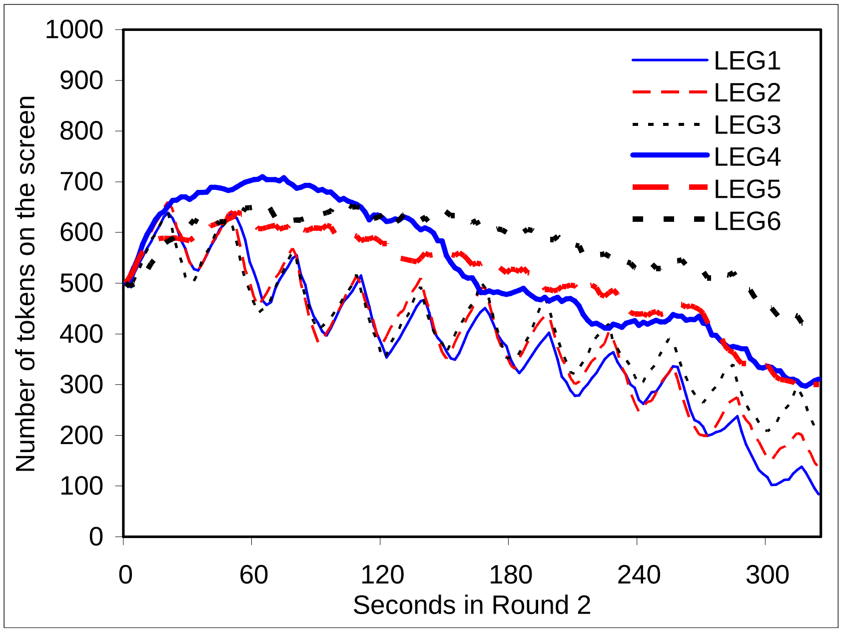

Figure 8. The number of tokens left in the renewable resource for the six groups of experienced participants whose communication occurred in a large group—combining all three groups—during the second round of the experiment.

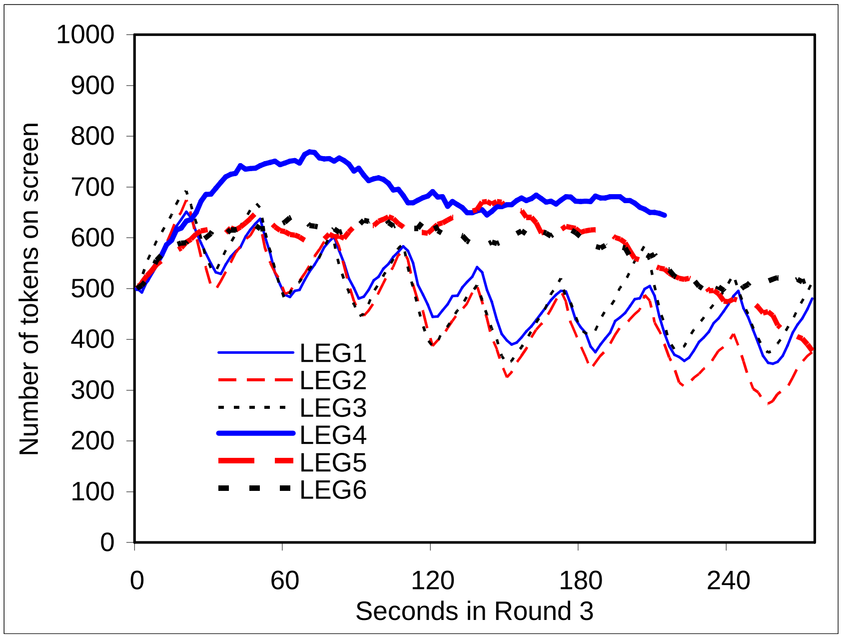

Figure 9. The number of tokens left in the renewable resource for the six groups of experienced participants whose communication occurred in a large group—combining all three groups—during the third round of the experiment. For experiment LEG4, the data on tokens in the resource left were not recorded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

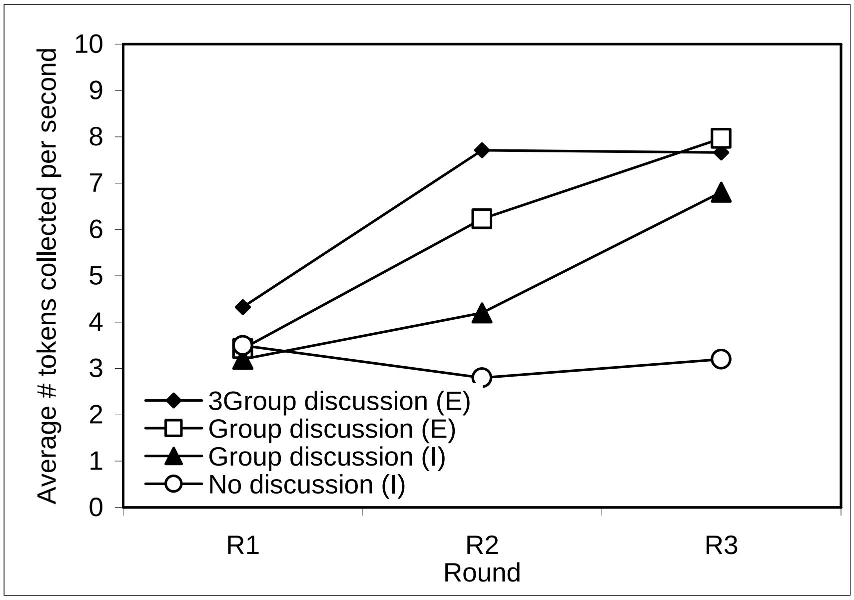

Figure 10. Average token collected per second per group for different experimental treatments. We scale it to group earnings per second to correct for different length of the rounds.

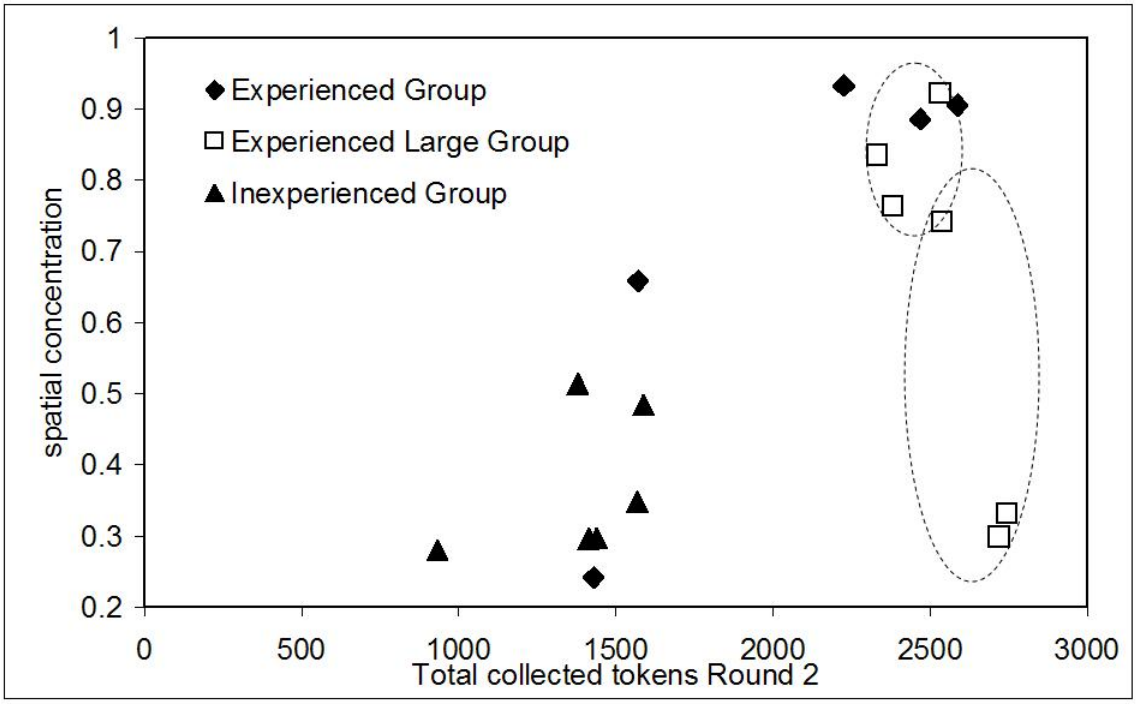

Figure 11. Spatial concentration index versus total collected tokens by groups in round 2 for three different treatments. The circles indicate which three groups where together in the communication experiment with three groups.

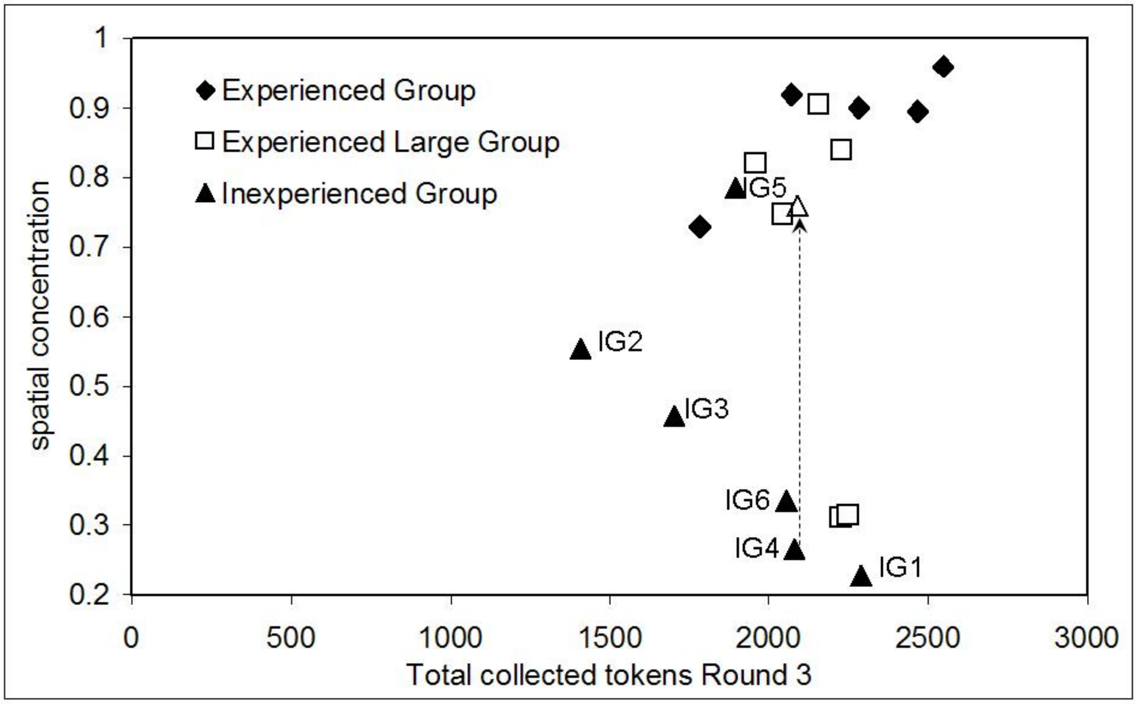

Figure 12. Spatial concentration index versus total collected tokens by groups in round 3 for three different treatments. IG1-IG6 indicate six inexperienced groups. Since in group IG4 the participants decided to split up the resource horizontally the spatial concentration is low in the original formulation. If we take into account that in IG4 the resource was split up horizontally instead of vertically, we get a higher spatial concentration for IG4, which is indicated in the figure by an arrow and a empty triangle.

Table 1. The four experimental treatments

Treatments (N of groups)	*Round 1*	*Discussion*	*Round 2*	*Discussion*	*Round 3*
1. Inexperienced participants (4)	Open access	None	Open access	None	Open access
2. Inexperienced participants (6)	Open access	In groups of five	Open access	In groups of five	Open access
3. Experienced participants (5)	Open access	In groups of five	Open access	In groups of five	Open access
4. Experienced participants (6)	Open access	One group of 15 participants	Open access	One group of 15 participants	Open access

Note: The number of groups observed is listed in parentheses.

Table 2. Statistics of linear regressions

	Collected tokens per second in round 2 (17 observations)	*Collected tokens per second in round 3 (17 observations)*
Constant	3.34 (1.11)	7.63 (3.63)***
Round 1	0.075 (0.26)	-0.21 (1.08)
Round 2		0.63 (3.02) **
Year	0.36 (0.47)	-0.75 (1.49)
Major	-1.49 (1.25)	0.92 (1.09)
Gender	0.64 (0.41)	-2.76 (2.64) **
Experience	1.88 (2.76) **	0.019 (0.03)
Three-group	1.47 (1.87) *	-0.98 (1.63)
R^2	0.78	0.72

Note: Rounds 1 and 2 refer to tokens collected by the group per second in round 1 or 2. Year refers to college program (freshman=1 . . . senior = 4). Major is 1 is monetary-oriented majors like business, economics, accounting; 0 others. Gender is fraction of male. Experience is 1 when participants have been in an earlier similar experiment. Finally, three-group is 1 when the group was part of a three-group discussion treatment. Significance levels: (***)1%, (**)5%, (*)10%. Shown in parentheses are the *t* statistics. The same format is applied in the following tables.

Table 3. Average token collected per second per group for different experimental treatments

	Round 1	*Round 2*	*Round 3*
Open access (I)	3.50 (0.45)	2.80 (0.49)	3.20 (0.47)
Group discussion (I)	3.20 (0.16)	4.20 (0.72)	6.80 (1.12)
Group discussion (E)	3.43 (0.50)	6.23 (1.60)	7.96 (1.11)
Three-group discussion (E)	4.33 (1.96)	7.71 (0.51)	7.66 (0.42)
Private property in round 2 (C)	3.30 (0.19)	4.21 (0.96)	3.58 (0.52)
Private property in round 2 (I)	3.20 (0.38)	4.39 (1.35)	3.34 (0.36)

Note: The numbers in parentheses are the standard deviations.