International Journal of the Commons
Vol. 2, no 2 July 2008, pp. 288–312
Publisher: Igitur, Utrecht Publishing & Archiving Services for IASC
URL:http://www.thecommonsjournal.org
URN:NBN:NL:UI:10-IJC-0801 4

ISSN: 1875-0281

Effect of rule choice in dynamic interactive spatial commons

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Abstract: This paper uses laboratory experiments to examine the effect of an endogenous rule change from open access to private property as a potential solution to overharvesting in commons dilemmas. A novel, spatial, real-time renewable resource environment was used to investigate whether participants were willing to invest in changing the rules from an open access situation to a private property system. We found that half of the participants invested in creating private property arrangements. Groups who had experienced private property in the second round of the experiment, made different decisions in the third round when open access was reinstituted in contrast to groups who experienced three rounds of open access. At the group level, earnings increased in Round 3, but this was at a cost of more inequality. No significant differences in outcomes occurred between experiments where rules were imposed by the experimental design or chosen by participants.

Keywords: Common-pool resources, institutional change, laboratory experiments, open access, private property

Acknowledgements: We appreciate the support of the National Science Foundation for the grant "Dynamics of Rules in Commons Dilemmas" BCS-0432894. Many people have been involved in this research. Robert Goldstone, Filippo Menczer, and Elinor Ostrom helped Janssen with the design of the 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, Elinor Ostrom, Pamela Jagger, and Frank van Laerhoven assisted Janssen in performing the experiments. Also, many graduate students, staff, and faculty pre-tested the experiments and we thank them for all of their help. Janssen did the data analysis with input from Takao Sasaki. We are appreciative of the excellent comments of two anonymous reviewers.

1. Introduction

Renewable resources are generally overharvested in the field and in laboratory experiments when there are no rules limiting who can harvest or how much (an open access situation). One method potentially available to resource users is to select their own institutional rules for governing the use of a shared resource. In this paper we study whether people invest their own resources in institutional change and the implications of an endogenous rule change when a common-pool resource (CPR) is shared. CPR problems provide a valuable analytical situation for exploring the construction of institutional practices because individual, material self-interest is pitted against the achievements of higher group returns. Open access is CPRs basic social dilemma in which individuals have an incentive to harvest the resource at such a rate that, if everyone harvested at this rate, a collectively disadvantageous outcome would result.

An example of such a social dilemma, known as "tragedy of the commons,'' was observed in the collapse of the northern cod of Labrador and Newfoundland during the early 1990s (Finlayson and McCay 1998; Finlayson 1994). The closure of the cod fishery adversely affected thousands of fishing families and related businesses along the entire eastern coast of Canada. In this instance, a national government exercised control over the fishery but did not sufficiently limit harvesting and even subsidized the acquisition of new vessels (Finlayson and McCay 1998: p. 320). In Maine, a dramatic contrast exists between CPRs where fishers have created strong rules to limit harvesting (in regard to lobster, see Acheson 2003) as contrasted to the lack of such rules (in regard to ground fish, see Dietz et al. 2003: Figure 1; Wilson 2002). A question of deep practical and theoretical importance is when, how, and why do the harvesters from a CPR resist overharvesting by imposing rules on themselves (as did the Maine lobster fishermen) as contrasted to continuing to overharvest (as did the Maine, Newfoundland, and Labrador cod fishermen).

During the last 20 years, controlled experiments have been used to test hypotheses about how individuals are able to share common pool resources (Ostrom et al. 1994). The findings indicate the importance of communication and opportunity to sanction for fostering higher levels of cooperation. Many social science experiments are performed with undergraduate students attending universities in the United States or Western Europe. Critics of using experiments with human subjects ask: How representative are such groups? Experiments conducted in one or two hours with subjects who are relatively young are limited in their ability to provide strong data about long-term processes, about specific cultural patterns, or about the behavior of much older subjects familiar with the challenge of governing a commons.

Recent experiments conducted with villagers living in remote regions of developing countries, however, have replicated findings obtained in laboratory-controlled social dilemma experiments. Cárdenas (2000) has, for example, replicated the core findings of extensive common-pool resource experiments conducted in the U.S. (Ostrom et al. 1994) with villagers living in remote regions of Colombia (see also Cárdenas et al. 2000). Because the Columbian villagers knew each other, rather than the anonymous conditions of the U.S. experiments, further information about relationships among small groups could also be studied. Henrich et al. (2004, 2006) report on experiments conducted in multiple field settings where the central tendencies of the research findings are similar to those obtained when participants are undergraduate students, but the variance is much higher and related to attributes of each local setting and the specific participants involved. Further, findings from laboratory settings about the importance of participants monitoring levels of cooperation have been substantiated by empirical field studies (Gibson et al. 2005; Hayes and Ostrom 2005; Ostrom and Nagendra 2006).

Previous experiments in the laboratory and in the field have used abstract descriptions of CPRs, where subjects invest and receive tokens according to clearly presented tables but normally without temporal and spatial dynamics. The main innovation of the experimental environment we have developed and used in this paper is the ability of participants to interact in real-time with others in a spatial and dynamically changing environment consisting of shared resource units. The environment used in these experiments – a computerized resource that appears similar to computerized games that college students have previously seen – enables the ability to represent space and time, but it is also broadly familiar to most participants in the experiments. Although the first experiments discussed in this paper used a relatively simple density dependent growth function, more complex environments will be investigated in the future. Over time, we hope to derive better insights about how resource dynamics affect the ability for groups to self-govern.

In experimental settings, one solution to social dilemmas has repeatedly been shown to involve permitting communication among the participants (Sally 1995). Experiments have found that face-to-face communication enables a group to attain higher levels of cooperative harvesting restraint (and resulting better payoffs) than predicted by game theory (Bouas and Komorita 1996; Ostrom and Walker 1991). A second solution is to allow participants to impose sanctions on other participants that overharvest the resource (Ostrom et al. 1992; Fehr and Gächter 2000; Gürerk et al. 2006; Carpenter 2000; Henrich et al. 2006). A third related solution that we explore in this paper (see also Kosfeld et al. 2006; Ostrom et al. 1992), is to give participants an opportunity to engage in the choice of a rule. In particular, we investigate whether being able to choose (at a cost to oneself) a rule that gives each participant a spatially explicit, imperfectly enforced private property to harvest from, increases the yield obtained from a renewable resource. We also inquire whether gaining the experience of overharvesting from an open-access resource enables users to learn better individual strategies for increasing their payoffs over time, even when they are not able to communicate with others about their experience.

2. Avoiding social dilemmas by changing rules

Most experiments on CPR problems constrain the range of actions taken by participants so as to test the effect of specific treatments on actions taken and on individual as well as joint outcomes. Participants choose how much to harvest a resource, and may additionally have the opportunity to monitor and sanction other participants. Only a few experiments, however, have provided participants with the opportunity to institute new rules that affect the incentives driving their own harvesting behavior.

One line of work is by Samuelson, Messick and colleagues on structural change of dilemmas (Samuelson and Messick 1995). In Samuelson and Messick (1986) a group of six participants shared a renewable resource. After 10 rounds of open access decisions, participants (without knowing who the others were or being able to communicate) had the opportunity to choose between continuing further with open access or an alternative rule. Depending on the experimental treatment, one of the following three rules served as the alternative: (1) the election of a leader, (2) the allocation of private property as equal shares of the resource capacity, or (3) the allocation of private property as shares proportional to each participant's harvest during the first 10 rounds. Although the participants were told to play against each other, deception was used and they were playing individually in different treatments. The treatments varied in regard to the feedback; participants perceived resource overuse in one treatment and optimal use of the resource by the group in another, with small or large variance in either case. When participants were experiencing an overuse of the resource, about 50 percent voted in favor of splitting the resource equally. When participants were experiencing unequal harvesting in the first ten rounds, they tended to vote for a leader (Messick et al. 1983) or other structures provided (Samuelson and Messick 1986). Most of the studies of Samuelson, Messick and colleagues stopped the experiment when a new rule was chosen, and thus their experiments did not analyze the after effects of the new rule.

Sato (1987) studied an artificial forest of slow growing trees harvested by four participants who did not know with whom they were interacting and could not communicate with one another. Participants with an equality rule – where costs were equally allocated among participants – experienced lower performance than those with a punishment rule, where those who take more from the resource pay a higher share of the costs. In the middle of the experiment, participants could choose between the punishment rule and the equality rule. After experiencing the equality rule, and thus lower performance, the punishment rule was chosen more often.

Sutter et al. (2005) studied four-person public good games. Participants had a choice to participate in a costly vote. Those who decided to participate in the vote could choose among a standard game, one with sanctioning, and one with rewards. Fifty percent of the participants chose the costly voting procedure. Contributions were higher if the participants chose the rule themselves instead of having it imposed by the experimenter. Those who voted for a rule contributed more (initially) than those who did not vote for it. Sutter et al. did not find a difference in the use of punishment and rewards between the imposed and the chosen rule change (see also Chan et al. 2002).

Kosfeld et al. (2006) examine whether groups of four players will choose to form an "organization" consisting of two to four players who pay a cost to join. If established for a round, "members" are required to contribute all of their allocated tokens to the provision of a public good as well as contributing a per-person share of the costs of the organizations. Each group had 20 opportunities to make this choice. Kosfeld and colleagues found that between 40 percent and 60 percent of the groups given this opportunity voted unanimously to change the rules and create an organization for the next round of pay.

2.1. The hypotheses of this study

In the set of experiments report herein, participants have the option to change the rules of the game. We provide the option of a costly vote like Sutter et al. (2005) to split the resource in equal parts and provide moderate enforcement of this rule by the computer. Since investing in a rule, which will only be implemented when the majority invests, is a threshold one-shot public good we expect that about half of the participants invest in the rule change as observed in threshold public good experiments (Bagnoli and McKee 1991; Marks and Croson 1999; Kosfield et al. 2006). Note that it is not evident for the participants that this is a public good since the benefits of splitting up the resource is not known.

H1: When given an opportunity to invest their own resources in changing access rules to private property, we expect about half of the participants will invest in rule change.

In line with the findings of Ostrom et al. (1992) and Sutter et al. (2005) we expect that those who invest in rule change, will do better over time and are more likely to obey the rules.

H2: Those who invest in the rule change, will collect more tokens after the rule change due to their own better management of their "private property" and are less eager to steal tokens from others.

The possibility of establishing new rules has not always led to better resource stewardship. Some scholars have found improved performance (Ostrom et al. 1992; Carpenter 2000; Sato 1987; Kosfeld et al. 2006), while others found the opposite (Bischoff 2007). In the experiment of Bischoff, individuals within groups each determined their desired number of fish to be removed from a lake over several rounds, but were also probabilistically penalized if they removed too many fish and a costly patrol caught them. Communication was allowed among participants at all times. Groups were either given a fixed rule that determined the patrol intensity, or were allowed to determine in the first round their own patrol intensity by majority or unanimous vote. The groups that were allowed to vote had significantly reduced average payouts to individuals compared to the groups with fixed patrol intensity. Bischoff conjectures that voting was disadvantageous because participants did not have experience with the game prior to voting and thus may not have voted from an informed perspective. (Voting for a rule change in our experiments occurred *after* experience in this environment.)

Although there are different findings in the literature, the majority of the studies suggest an increase of the performance after a voluntary rule change. Therefore we propose the following hypothesis.

H3: The performance of groups will increase after a rule change.

If individuals who invested in rule change are more eager to cooperate (H2), we may expect a self-selection of groups. In groups where the majority invested in rule change, higher levels of returns might be experienced compared to random groups who have imposed rule changes (Tyran and Feld 2006).

H4: Groups with chosen rule change will experience higher returns compared to those groups who have a rule change imposed.

In order to be able to tell whether observed differences in behavior are the result of rule change or learning, we need to perform experiments to tease out learning effects vs. effects of rule change.

H5: Changes between treatments are a consequence only of the rules used in the round, not a consequence of learning behavior.

The purpose of the experiment described in the current paper is to build upon previous research, exploring how allowing for the choice of rules facilitates or interferes with effective group harvesting of resources. Unlike Bischoff (2007), we sought to give participants experience with the environment and cost structure before providing them with an opportunity to choose a rule. Unlike some other studies (Samuelson and Messick 1986), we are principally interested in the global harvesting patterns that emerge when people interact in groups and may be affected by each other's under and overharvesting. Accordingly, our participants interact with each other in a common setting rather than interacting with preprogrammed participants.

2.2. The experimental settings

A final unique aspect of our experiment is that we try to create a natural resource harvesting situation with continuous opportunities for repeated decisions regarding the speed and amount of harvesting within rounds of approximately four minutes, and with an intuitive, interactive way to harvest. Rather than explicitly expressing numerical amounts of resources to harvest in a limited number of individual decisions, participants spontaneously move in a two-dimensional virtual environment. Resources are harvested by moving in this environment. Such a dynamic, spatial, and interactive environment provides us with a natural experimental platform for exploring spatial foraging strategies (Goldstone and Ashpole 2004), the influence of moment-by-moment changes in other participants' foraging patterns (Goldstone et al. 2005), the temporal dynamics of harvesting decisions (Kraft and Baum 2001), and realistic rules such as property rights based on spatial boundaries.

3. Experimental design

We designed an experiment[1] to test the hypotheses described in the previous session. In the experiment, groups of five participants share a renewable resource that grows on a 20×50 grid of cells replicated on each participant's computer screen (Figure 1). They were told that they can collect tokens during three rounds, but the exact length of the rounds where not known to the participants. Note that a round here is defined as a period of time during which participants can make many decisions. Each participant harvests green tokens by moving a virtual avatar's location on top of the tokens, then pressing the arrow keys (left, right, up, and down) on the keyboard. Each harvested token is worth \$0.01. The resource replenishment rate is *density dependent*. The probability $p_c(t)$ that a green token will appear in an empty cell c at time t is

[1] The instructions for the experiment and the questionnaire that we used are available upon request from the first author.

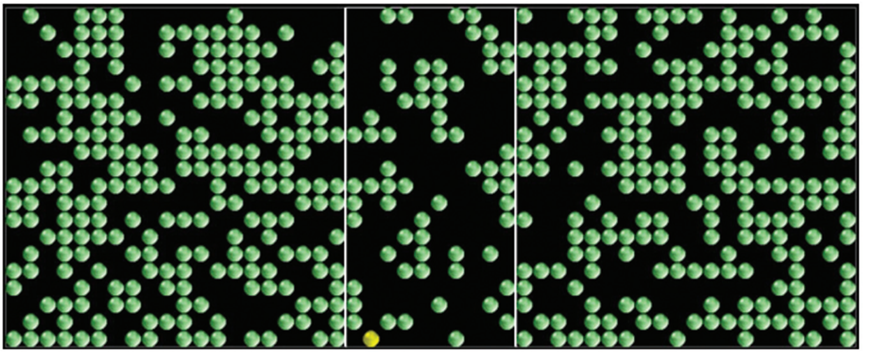

Figure 1: Screen view of the renewable resource, where the green tokens represent the resource, black cells are empty, the yellow dot is a participant's avatar, and the white lines demarcate the property lines for this participant. Not shown here, but in blue dots in the multiplayer experiment, are the locations of the four other participants' avatars. Green tokens appear on empty cell probabilistically, with a higher chance when the empty cell has more neighbors with green tokens. When there are no neighbors with tokens, an empty cell cannot be replenished. The participant can move their yellow avatar around by using the arrow keys.

proportional to the fraction of neighbor cells that contain green tokens at the previous time step (Figure 2):

$$p_c(t) = p\frac{n_c(t-1)}{N}$$

where $n_c(t-1)$ is the number of neighboring cells of c containing a green token at time $t-1$, and N the total number of neighboring cells ($N=8$ for every non-edge cell as we use a Moore neighborhood). The parameter p is defined in such a way that the replenishment of the resource is fast enough to be observed by the participants, but sufficiently slow that the participants experience a dilemma between individual and group interest. If participants collect as many tokens as they can, there will quickly be no tokens remaining on the screen. This is illustrated in Figure 2. Once every token has been harvested, there is no further chance of resource replenishment.[2]

[2] Considerable time and energy was spent in developing the software for these foraging experiments as we expect that multiple, future experiments will utilize this type of spatial, real-time experimental software. The advantage of using this type of software is that the participants are interacting directly with an observable resource system. We know that participants, who participated in earlier experiments related to common-pool resources (Ostrom, Gardner, and Walker 1994), did understand the experiment, since substantial time was devoted before each experiment explaining the verbal and mathematical representations of a renewable resource and testing them to insure that they had a good comprehension of the structure of the experiment. Critics are not always convinced that a tabular payoff table is a good representation of a common-pool resource.

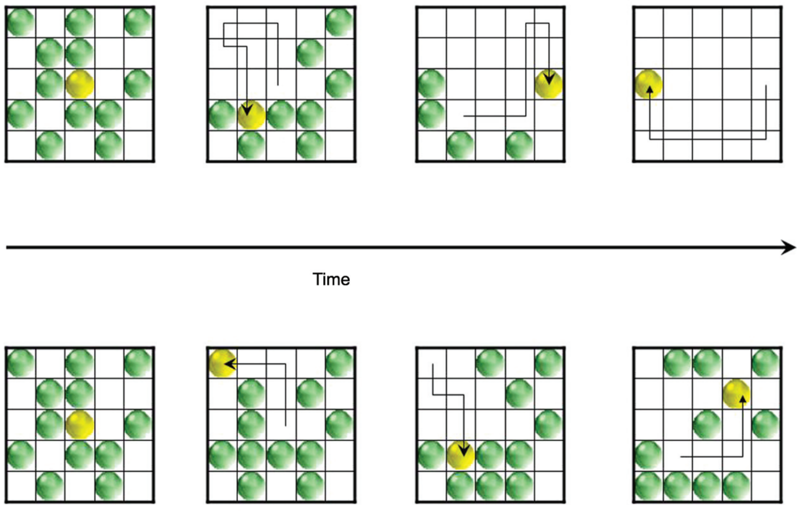

Figure 2: Four snapshots of two types of participants in a hypothetical situation of a 5×5 resource grid. In the top case, the participant moves its avatar 8 cells per time step. There is almost no time for regeneration, and the participant overharvests the resource after the fourth snapshot. In the bottom case, the participant makes the same moves but at a slower pace of only 4 cells per time step, giving the resource a chance to be replenished by leaving enough tokens available. After 4 time steps, the resource density has not significantly declined.

We began the experiment with an explanation of the replenishment rules of empty cells illustrated with examples. We then allowed sufficient time for a practice round in which we asked 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 would observe the resource replenishment process and its dependency on currently visible tokens. After this practice round, there was a first round with open access conditions. Participants could harvest tokens from any location on their shared resource – the entire screen. Initially 50 percent of the environment cells were seeded with tokens. After the first round used in all of the experiments reported on herein we employed different treatments (Table 1).

The first treatment was to continue with open access for all three rounds. The second to impose a private property rule between the first and second round. This private property rule included the demarcation of one-fifth of the resource (see Figure 1) in the middle of each participant's screen.[3] We chose to use private property as one of the frequently used, simple rules for solving collective action problems in real life situations; we will explore the choice of

[3] Each participant had a different view on the resource during the whole experiment in order for that participant's private property to be located in the middle of the screen.

Table 1: Different treatments of the experiments. The number of observations is shown in parentheses.

Treatment (groups)	Round 1	Rule investment	Round 2	Round 3
No private property (4)	Open access	n/a	Open access	Open access
Private property imposed (9)	Open access	n/a	Private property	Open access
Private property chosen (9)	Open access	>50%	Private property	Open access
Private property not chosen (11)	Open access	<50%	Open access	Open access

other rules in future experiments. Note that participants can still harvest tokens from areas assigned to other participants. If a participant harvests a token outside of their spatially defined property there is a probability of 10 percent that the cheater is caught by the computer for each illegally harvested token. 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 first time a participant is caught, the penalty is 5 tokens, and the second time the penalty increases to 10 tokens. Each subsequent time the participant is caught a penalty of 15 tokens is imposed. The participants are fully informed on the consequences of illegal harvesting.

The third treatment was to allow the participants to vote on the property rule. The property rule was presented to the participants and they were asked whether they would invest 50 tokens to implement this rule. Only when three or more of the five participants invested these 50 tokens was the property rule implemented. Otherwise, the participants who voted for the rule lost their 50 tokens, and the property rule was not implemented. Hence, in our analysis we assign Treatment 3 to those groups where the private property rule was chosen and Treatment 4 to those groups where the participants did not chose to change rules from open access.

In the third round of the experiment, all four treatments returned to open access, whether or not a private property rule was imposed or chosen in the second round. At the end of the experiment, participants filled in a survey while the experimenter prepared the payments. We asked participants a short set of questions about their major, gender, experience with video games, number of hours they worked during the school week, and 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 agent to harvest about two tokens per second without making big open spaces. This strategy would keep the average density of the tokens to 50 percent evenly distributed in the environment. This would lead to a harvest of 2 tokens per second. Since the duration of the rounds varies (270 seconds, 330 seconds and 280 seconds), the long term optimal harvest per person per round would be about 540 tokens in round 1,660 tokens in round 2 and 560 tokens in round 3. If all members of the group followed such a cooperative rule of thumb, each participant would earn, between $22 and $23 including a $5 show up fee. Note that we assume no end of round effect here since the computer was programmed to end each round randomly around 4 minutes. If the participants correctly anticipate the end of the round and harvest all the tokens just before the round ends, the earnings could be about $5 higher.

4. Results

We performed a series of experiments from October 24, 2005 to November 4, 2005 in the Interdisciplinary Experimental Laboratory at Indiana University. The participants where recruited randomly from the database of the Interdisciplinary Experimental Laboratory of undergraduate students at Indiana University. Thirty-three groups of 5 participants each were involved in the experiment, for a total of 165 participants. The average age of participants was 20.1 years. Half of the participants were female. Of the 20 groups who participated in the rule investment experiments, 9 groups elected the rule and 11 did not. Thus, as we hypothesize in H1 about one half of the group selected the rule.

4.1. Round 1

Figure 3 shows that all groups depleted the renewable resource rapidly,[4] although at a variable rate. On average it took 82 seconds to harvest *all* of the tokens from the screen leading to an average amount of 180 tokens collected per person. Compared with the rule of thumb behavior described above, this means that participants earned on average only about one fourth of the potentially feasible earnings. Then, the participants had to watch the empty screen for the remaining time (on average about 2.5 to 3 more minutes). We decided not to stop the round when the resource was depleted to provide the participants a vivid experience of the lost opportunities that stemmed from overharvesting. The longest duration before the resource was fully depleted was 2 minutes – several groups depleted all tokens in about 70 seconds.

The amount of tokens collected varied both across the whole population of participants as well as within each group (Figure 4). To illustrate the variation within groups, the tokens harvested by each participant were normalized by the amount of tokens collected by each group before the resource was depleted. The average share is necessarily 20 percent, but the variation is considerable; a few agents harvested almost no tokens in the first round. Figure 5 shows that the variation within a group is related to the number of tokens collected by the whole group (this relation is statistically significant[5]). A higher variation

[4] When we brought participants back to the laboratory after they had participated in one experiment and had them participate again in a different treatment but with the same first round, there was no significant difference in their behavior as contrasted with their first experiment. We conclude that overharvesting is not a consequence of lack of understanding of the experimental environment.

[5] In this analysis we use a significance level of 10 percent as our cutting point between lack of significance and significance.

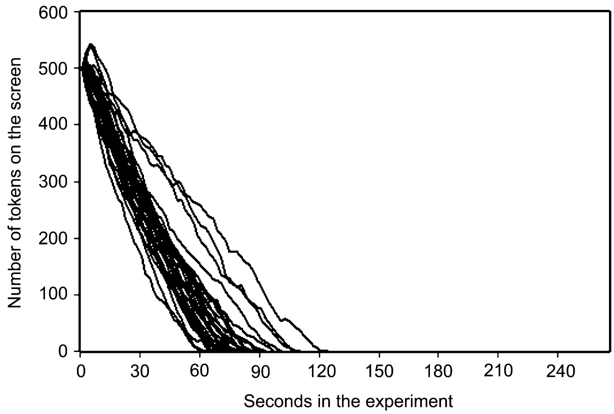

Figure 3: The number of tokens left in the renewable resource for the 33 groups during the experiment. This statistic was recorded every 2 seconds.

includes participants who did not harvest many tokens since they moved their avatar slowly on the screen. This resulted in slower overharvesting of the resource and a higher replenishment rate, leaving more tokens to be collected by the other, more selfish participants. It is therefore little surprise that groups with more variation collected more tokens, even though the participants did not collaborate or coordinate in a strict sense. If genuine coordination and collaboration were occurring, participants would be able to harvest more in a round due to slower harvesting rates. In this situation, however, each participant experiences the temptation to get a higher share by increasing the speed of their own harvesting rate. Hence the dilemma this experiment presents to the participants.

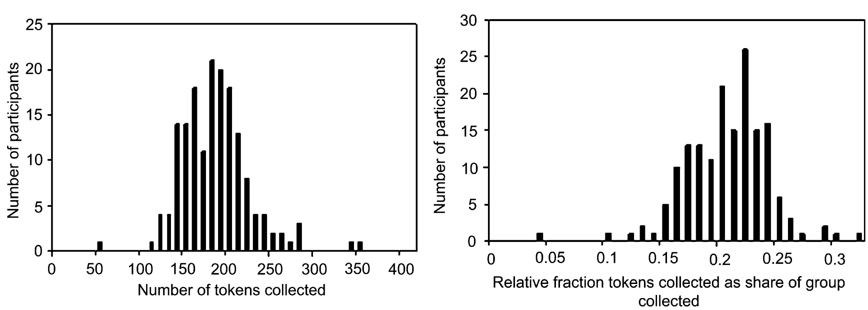

Figure 4: Distribution of tokens collected in round 1 by the 165 participants, as a total count (left) and as a share of the total amount of tokens collected by each group (right).

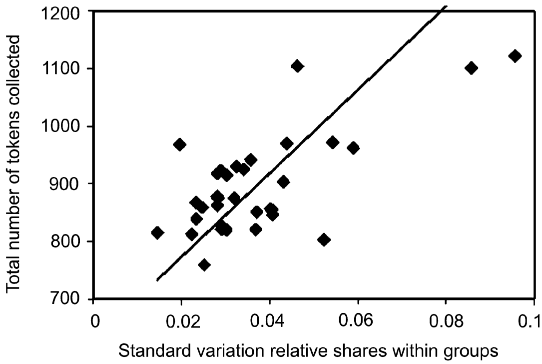

*Figure 5: For each group the standard deviation of relative shares of tokens collected is plotted against the number of tokens collected by the whole group. The figure also includes a linear regression (tokens = 627.8 + 7258*standard variation) with $R^2 = 0.49$ and a significant correlation between both axes ($p < 0.00001$).*

Now we can ask: What are the attributes of the participants that affect their harvesting rate in round 1? Table 2 reports the results of a regression analysis. Gender and size of high school are found to be significant factors. Male participants have relative higher earnings in the first round compared to female participants. Those who went to a larger high school also collected more tokens in the first round. Other factors like major and time spent in playing video games, had no significant effects.

4.2. Round 2

Four different treatments were implemented in round 2: open access (the same as in round 1), an imposed private property rule, and the two outcomes from voting for a property rule (property rule selected or not). When participants had the choice to invest in the private property rule, 46 of the 100 participants invested 50 tokens to make a positive choice for the rule. In 9 of the 20 groups that had the option of investing, a majority of participants voted to implement the rule. These results support H1.

More tokens were obtained when a group implemented the property rule compared to when they did not (278 vs. 178 per person, one way ANOVA, $F(1,18) = 23.2$, $p = 0.00014$), and the resource also lasted significantly longer (290 vs. 86 seconds, one way ANOVA, $F(1,18) = 62.2$; $p = 0.000002$). This supports H3.

When private property was imposed in round 2, the performance of those groups increased as well, and there is not a significant difference between chosen and imposed implementation of rule. The number of tokens collected with chosen vs. imposed rule was 278 vs. 289 (One Way ANOVA, $F(1,16) = 0.21$, $p = 0.66$), while the number of seconds until the last token

Table 2: Statistics of linear regressions. Year refers to college program (freshman=1 ... senior=4). Major is 1 is monetary oriented majors like business, economics, accounting; 0 for others. Gender is (1 for female). Ln (1+work) is the natural logarithm of the number of hours a participant worked per week. Ln (1+video) is the natural logarithm of the number of hours a participant played videogames per week. Finally, school is the number of students at high school. Significance levels: (***)1%, (**)5%, (*)10%. Shown in parentheses are the t statistics. The same format is applied in the following tables.

	Fraction 1 (153 observations)
Constant	0.214 (18.9)***
Year	-0.002 (0.78)
Major	0.004 (0.70)
Gender	-0.023 (3.46)***
Ln (1+work)	-0.003 (1.40)
Ln (1+video)	-0.002 (0.52)
School	0.008 (1.91)*
R^2	0.155

collected was 290 vs. 319 (One way ANOVA, $F(1,16)=1.22$; $p=0.29$). As such, we can reject H4.

When the rule was not implemented or the participants had no option to implement the rule, the number of tokens collected in the second round was not significantly different from the number collected in the first round. We do find significant differences between participants who invested in rule change and those who did not. If we restrict our attention only to the groups that voted for the rule, then the individual participants who invested in the rule change collected 129 more tokens in round 2 compared to round 1, as opposed to an increase of only 34 tokens for those participants who did not invest in the rule change (One way ANOVA, $F(1,43)=8.18$, $p=0.007$). This supports H2. When the private property rule was not implemented, those who invested in the rule change derived 5 tokens less, while noninvestors derived 2 tokens more, but this difference is not significant (One way ANOVA, $F(1,53)=0.45$, $p=0.51$).

Finally, we look at how individual "properties" were maintained. Each property had a maximum capacity of 200 tokens. An optimal harvest level to maximize replenishment would leave 100 tokens on the property and yield 2 tokens per second, or about 660 tokens on average over the duration of a round. Figure 6 shows the number of tokens collected (excluding penalties) versus the average number of tokens on individual properties. Only a few properties were maintained optimally. In two cases there was underharvesting, where the participants left too many tokens on the property. We see a linear relationship between the average number of tokens on the property and the number of tokens collected, and this is statistically similar for imposed properties and properties in which participants invested.

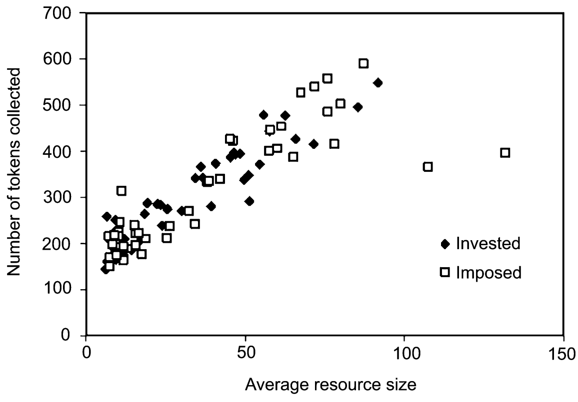

Figure 6: Number of tokens collected in round 2 vs. average resource size on their individual plot, for each participant in experiments with private properties.

4.2.1. Difference between imposed and chosen private property rule

To correct for group effects we measured the number of tokens collected by an individual as a fraction of the group harvest. We find that the fraction of tokens collected in round 2 is principally influenced by whether a participant invested in the rule change which supports H2 (Table 3). When the private property was imposed, we find a small effect of participants' major; participants who study subjects where rational choice plays a prominent role (economics, accounting, business) derived more tokens. We included the relative share of tokens collected in round 1, to see whether there is a spillover effect from experience in round 1 to round 2. We did not find the relative fraction of round 2 and 1 to be significantly related (which supports H5).

4.2.2. Who invested in the rule change?

We performed various analyses using Probit models to explain who invested in the rule change, but did not find statistically significant differences. When asked about the reasons for investing in the rule change, most participants mentioned the desirability of controlling their own property and trying to achieve better results for themselves. Only 20 percent of the participants who invested in the rule change mentioned that it would lead to better results for the whole group. For those who did not invest in the rule change, 50 percent did not see a benefit for the private property rule, and 30 percent hoped that a sufficient number of others would invest in the rule change. When a participant invested in the rule change, but an insufficient number of others did, 16 of the 17 participants indicated that they would invest again given a new opportunity.

Table 3: Statistics of linear regressions including the relative fraction of tokens collected in round 1. Invested is 1 when participants invested 50 tokens into the private property rule. The other variables and formats are the same as in Table 2.

	Elected rule fraction 2 (42 observations)	Imposed rule fraction 2 (44 observations)
Constant	0.146 (1.98)**	0.290 (3.64)***
Fraction 1	0.173 (0.58)	-0.503 (1.52)
Year	-0.011 (1.354)	-0.001 (0.07)
Major	0.008 (0.47)	0.041 (1.72)*
Gender	0.006 (0.26)	-0.016 (0.65)
Invested	0.06 (3.095)***	
R^2	0.234	0.139

4.2.3. Stealing behavior

When the private property rule is implemented, participants may "steal" from other properties. We do not find a difference between imposed private property and chosen private property rules in terms of the extent of stealing behavior. When the rule was chosen, the average number of tokens stolen was 16.5 per person compared to 16.0 when the rule was imposed (One way ANOVA, $F(1,88)=0.001$, $p=0.92$). Those participants who did not invest tokens in the rule change stole more tokens than those participants who did invest in the rule change, 19.0 vs. 15.4, but this was not a significant difference (One way ANOVA, $F(1,43)=0.3$, $p=0.59$).

Due to the increasing costs of imposed sanctions in the computer-monitored, property right regime, a participant could earn an expected 0.5 token per stolen token when they had not yet been caught for the first time. When a participant has been caught once, the expected benefit of stealing an additional token is zero. After being caught twice or more, an expected *loss* of stealing another token equals 0.5 token. Therefore, a selfish rational agent would steal some tokens until caught for the first time. Figure 7 shows that 30 percent of the participants never stole a single token. Continuing to steal tokens after being caught twice is also not rational due to the expected loss. Yet, 20 participants were caught more than 2 times (Figure 8), and therefore lost money on average by stealing additional tokens.

Where did the participants steal tokens? Figure 9 shows that this occurred mainly in the border area of a neighbor. It was very unlikely for participants to steal tokens that were more than a few cells into the property of a neighbor. When performing a regression analysis, we find that participants are increasingly likely to steal tokens as the average number of tokens on their neighbor's property increases (Table 4). Participants do not tend to steal from others who steal from them. This suggests that it is imbalance in tokens at their property edges, rather than retaliation, which drives stealing behavior in this experimental design.

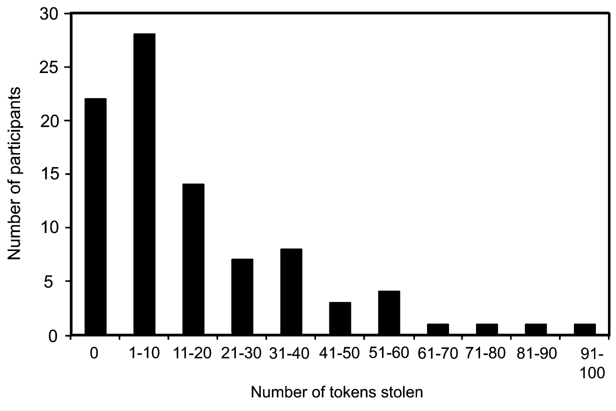

Figure 7: Distribution of the number of tokens participants collected from other properties.

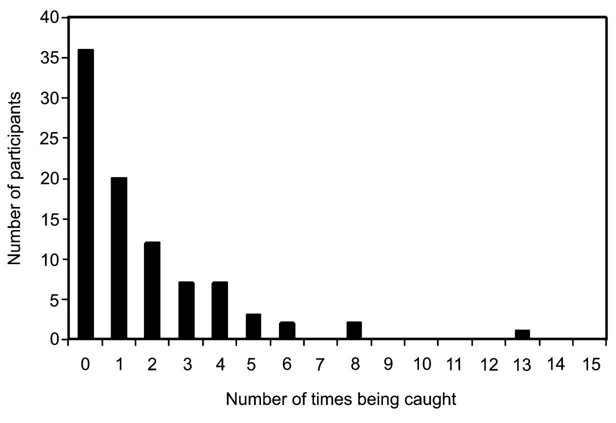

Figure 8: Distribution of the number of times participants were caught stealing tokens.

4.3. Round 3

In round 3, open access was implemented for all treatments. In many groups the resource was depleted as rapidly as in round 1. When round 2 did not have the property right rule, the average number of tokens collected in round 3 is not significantly different than in round 2 or round 1. Thus, simple experience in harvesting the resource did not lead to cooperative behavior. When round 2 had the property right rule, however, the average number of tokens collected is much higher in round 3 than in round 1 (1390 vs. 1002, One way ANOVA,

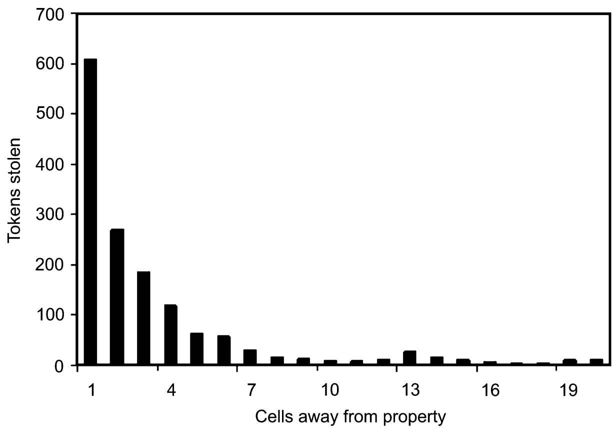

Figure 9: Distribution of the distance between stolen tokens and a participant's property.

$F(1,16) = 11.05$, $p = 0.004$ and 1447 vs. 935, One way ANOVA, $F(1,16) = 11.34$, $p = 0.004$, when the property right rule was chosen or imposed, respectively). We do not find a statistically significant difference among imposed or chosen settings.

Comparing the number of tokens collected in round 3 with round 1, we find that groups who had the option to invest in property rights derived higher earnings in round 3 compared to round 1 when the group invested in the rule (1002 vs. 892, One way ANOVA, $F(1,16) = 4.54$, $p = 0.049$), which was not significant when private property rule was imposed (935 vs. 864 One way ANOVA, $F(1,16) = 2.25$, $p = 0.15$). When we look at the time to collect the last token, the increase of time is significant in both chosen (138 vs. 81, One way ANOVA, $F(1,16) = 4.72$, $p = 0.045$) and imposed private property (93 vs. 76, One way ANOVA, $F(1,16) = 5.14$, $p = 0.038$). This suggests a learning effect and rejects H5.

What affected the relative share of tokens collected in the third round? In Figure 10, we see the tokens collected (not including the penalties in round 2 when the rule was implemented) for different conditions. We distinguish whether a participant voted "yes" or "no" and whether the rule was implemented. "No" voters harvested more in the first and third rounds compared to the "yes" voters. It appears that "yes" voters reduced their harvesting even when the rule was not implemented. Their strategy favored the "no" voters. "Yes" voters achieved a significantly higher token harvest, however, when the rule was implemented. In the third round, "yes" voters seemed to continue a conservative rate of harvesting when they had the rule implemented in round 2; this also benefited the "no" voters, who collect large numbers of tokens.

Table 4: Statistics of linear regressions of number of tokens stolen including whether a participant invested in private property (0 or 1), the number tokens stolen from the participants property in round 2, and the average difference in tokens on the property of the participant and its neighbors. Formats are the same as in Table 2.

	Tokens stolen (invested private property) 45 observations	Tokens stolen (imposed private property) 45 observations
Constant	0.16 (0.02)	10.1 (1.99)*
Invested in	0.79 (0.12)	
Number of tokens stolen from own private property	0.22 (1.29)	-0.51 (0.37)
Average number of tokens of neighbors – average number of tokens on own property	0.002 (3.07)***	0.001 (2.7)***
R^2	0.16	0.21

When we perform a regression analysis to predict relative share of one member of a group of five in round 3, we see that the relative share in round 2 has a negative impact on the relative share in round 3, as well as whether the participant invested in the rule change (Table 5). Participants whose academic major focuses on monetary issues tended to obtain a larger relative share of group payoffs in round 3. When the private property rule is imposed, the relative share in round 1 has a positive effect and the relative share in round 2 has a negative effect on a participant's relative share in round 3. Investment in rule change is not possible in the imposed private property rule conditions, but the positive effect of the relative share in the first round is consistent with the results of the chosen private property rule. Those who are doing relatively well in round 1 do relatively well in round 3.

Finally, we observe an increase in variance of relative shares in round 3 compared to round 1 when participants have experienced private property in

Table 5: Statistics of linear regressions including relative fraction of tokens collected in round 1 and 2. Other variables and formats are the same as in Tables 2 and 3.

	Elected rule fraction 3 (42 observations)	Imposed rule fraction 3 (44 observations)
Constant	0.221 (3.64)***	0.044 (0.76)
Fraction 1	0.259 (1.097)	1.002 (4.68)***
Fraction 2	-0.347 (2.69)**	-0.223 (2.24)**
Year	0.005 (0.72)	-0.008 (1.12)
Major	0.029 (2.059)**	0.029 (1.87)
Gender	-0.003 (-0.16)	0.011 (0.70)
Invested	-0.042 (-2.69)**	
R^2	0.459	0.501

round 2 (0.057 vs. 0.036 One way ANOVA, $F(1,34)=6.55$, $p=0.015$). There is no significant difference when they have not experienced private property in round 2. This confirms the indication given in Figure 10 that there is a divergence in behavior in round 3 between participants who invested in a rule change and those who did not. Although the aggregated statistics suggest that experience with private property leads to better performance of the group in round 3, there is actually an increase of inequality within the groups. Participants who voted against the rule receive higher payoffs than those who voted for the rule.

5. Discussion

A novel, real-time, and spatially explicit renewable resource experiment was used to study the effects of endogenously made choices or exogenously imposed rule changes in a commons dilemma environment. This experimental environment provides many more opportunities for individual decisions than deciding on harvest levels 20 to 25 times – as is the case in traditional 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.

Our primary interest has been to investigate whether participants were willing to invest in a rule choice, and how this decision affects the resource use. We found that about half of the participants who were given a choice were willing to invest an average of 30 percent of their earnings from the first round to change from the open access situation of the first round to a form of private property in the second round. We view these investments as contributions to a

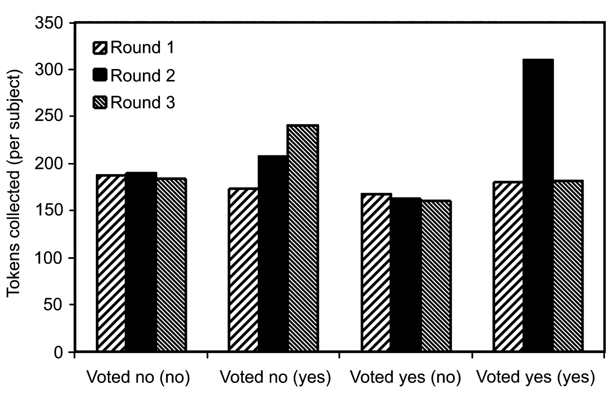

Figure 10: Average tokens collected per individual for the different types of situations: whether the individual voted in favor or against the rule, and (in parentheses) whether the rule was elected or not. The figure only includes data where participants where allowed to invest in a rule change in round 2.

threshold public good game with uncertainty, where the public good is the new property system. The threshold is obtaining more than 50 percent of the votes in favor. The uncertainty relates to the benefits that may or may not be obtained from choosing the private property regime.

Our results are consistent with the findings obtained in threshold public good experiments (Bagnoli and McKee 1991; Marks and Croson 1999). Marks and Croson (1999) found a successful provision (meeting the threshold) in half the cases even when the benefits of the public good were uncertain. Our results are also consistent with public good experiments with heterogeneity in endowment, the earnings of the first round of our experiment. Earlier studies found that those who have a high initial endowment, under-contribute relative to their share of wealth, and those with lower endowments over-contribute relative to their share of wealth (Chan et al. 1999; Cherry et al. 2005). Our results are also consistent with the study of Sutter et al. (2005) on institutional choice, where those who invested in rule change are initially more cooperative in resource use.

We did not find a difference in cheating behavior (stealing tokens) between imposed or chosen private property regimes, nor between those who invested in a rule change and those who did not invest. This latter finding is consistent with Sutter et al. (2005) who found no difference in the use of punishment between those who voted in favor of the use of punishments and those who did not vote in favor.

We did not find a significant difference in appropriation levels between imposed and chosen institutional settings. This contradicts some earlier findings of Cárdenas et al. (2000) and Sutter et al. (2005), who found settings with chosen rules experience higher levels of cooperative behavior than when rules were imposed. Experience with private property did lead to improved group performance in the third round. This improved performance is the results of the more cooperative behavior of those participants who invested in the property rule and also managed their private property better in round 2. The participants who did not invest in the private property regime do tend to free ride on the more cooperative behavior of others. The slower rate of resource appropriation and increased regeneration provides more tokens for the whole group, especially those who did not slow down their harvesting rate. This leads to an increased inequality within the groups in the third round. Although experience with a more productive institutional rule (private property) leads to a change in behavior, we cannot directly conclude that this experience leads to better results for the group.

The results indicate both a surprising lack of spontaneous learning but also an influence of the exposure to alternative strategies. On the one hand, there was no evidence that those groups, which were never exposed to harvesting under property rights, spontaneously learned to limit their own harvesting rates. Even after experiencing the complete eradication of their resources for two rounds, these groups were just as likely to quickly exhaust all available resources on a third round. On the other hand, when participants either voted for private property or had this rule imposed on them, there was evidence for transfer of this experience to the third round when the rule was lifted. This transfer, however, was far from complete. These groups did not perform as well after the rule was lifted as they had performed while it was in effect. Furthermore, the learning transfer was not universal and free riders took advantage of the learners' self-imposed limits on harvesting rate. For this reason, the advantage for groups experiencing the advantages of a private property rule may not be prolonged nor stable once the rule has been withdrawn.

An apparently large factor that determined participants' investment in the property rule was their appreciation for how the rule would benefit their own outcomes. Participants who voted for the rule benefited more from the rule than other participants who harvested under the rule but did not vote for it. Appreciating the nature of the resource replenishment and hazards of overharvesting apparently led some participants to pay resources to vote for the property right rule, and also use the opportunity to take more advantage of the property rights once established. Appreciating the nature of the game is not sufficient for efficient resource use, however, as was poignantly shown in the third round, when participants who voted for the rule earned lower payoffs than participants who did not. It would appear that participants' understanding must be united with the possibility of organization-building for robust and large improvements to group performance to be achieved.

The spatially explicit real-time commons provides a rich experimental environment for the study of common-pool resources. Our basic findings are consistent with more traditional studies, but we also found two interesting new results. First, imposing private property on participants did not lead to different behavior during the round that the rule was imposed than when participants decided on this rule themselves. This contrasts with earlier results which shows that imposing a sanctioning system leads to different behavior compared with chosen rules. Second, experience with an effective institutional arrangement may lead to more inequality when this institutional arrangement is changed again.

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