EFFECT OF RULE CHOICE IN DYNAMIC INTERACTIVE SPATIAL COMMONS

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Abstract
This paper addresses the option of endogenous rule change as a 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 such a public good. Groups who had experienced private property in the second round of the experiment, made different decisions in round 3 where open access was instituted again in contrast to groups who experienced 3 rounds of open access. At the group level, earnings increased in Round 3, but this was at a cost of more inequality. Furthermore, we found no significant differences between experiments where rules were imposed or chosen.
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Introduction

Renewable resources are generally overharvested in the field and in the lab when no rules limit who can harvest or how much (an open access situation). One method frequently available to resource users is to develop institutional rules for governing the use of a shared resource. In this paper we study how and why people develop such institutional rules.

The framework in which we carry out our exploration is that of common-pool resources (CPRs). CPRs are defined by two key characteristics: (1) it is costly to exclude potential beneficiaries, and (2) the resource units harvested by one person are subtracted from the pool of units available to others (Ostrom et al., 1994). The first attribute is shared with public goods, the second with private goods. CPR problems provide a valuable analytical situation for exploring the construction of institutional practices because they inherently pit individual self-interest against the greater good. CPR problems are basic social dilemmas 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

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early 1990s (Finlayson & McCay, 1999; 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 & McCay, 1999: 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: fig. 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).

In experimental settings, one solution to social dilemmas has been shown to involve permitting communication among the participants (Sally, 1995). Experiments have indicated that face-to-face communication can allow a group to attain higher levels of cooperative harvesting restraint than predicted by game theory (Bouas & Komorita, 1996; Ostrom & Walker, 1991). A second solution is to allow participants to impose sanctions on other participants that overharvest the resource (Ostrom et al., 1992; Fehr & Gächter, 2000; Gürerk et al., 2006; Carpenter, forthcoming). A third possible solution, explored here, 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 a rule that gives each participant a spatially explicit, private property from which to harvest increases the yield they obtain from a renewable resource. We also inquire whether gaining the experience

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of over-harvesting from an open-access resource enables users to learn better individual strategies for increasing their payoffs over time when they are not able to communicate with others about their experience.

### 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 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 & Messick, 1995). In Samuelson and Messick (1986), a group of 6 participants shared a renewable resource. After 10 rounds of open access decisions (without knowing who the others were or being able to communicate), participants 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, manipulation 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 treatment, 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 of 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 & 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 effect of the new rule once chosen.

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 experienced lower performance than those with a punishment rule. Participants could choose in the middle of the experiment between the punishment rule and the equality rule, and chose the punishment rule more often when they had experienced the equality rule, and thus lower performance, themselves.

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 participant 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. Sutter et al. did not find a difference in the use of punishment and rewards between the imposed and the chosen rule change.
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), while others found the opposite (Bischoff, in press). In the experiment of Bischoff, individuals within groups each determined their desired number of fish to remove 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 any time. 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. The author 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.

In a series of field experiments, Cárdenas et al. (2000) conducted a series of CPR field experiments each with eight villagers living in rural Colombia. The experiment was designed to be as similar as feasible, given the field setting, to the experiments reported in Ostrom et al. (1992; 1994). After nine rounds in which each participant had made a private, independent harvesting decision with feedback about the aggregate sum of all of their decisions, ten groups of 8 participants were able to have face-to-face group discussions before making the next ten rounds of anonymous decisions. Another five groups were told that an external regulation would be established in an attempt to improve group earnings. In the case of the external regulation, the participants were informed that making a decision consistent with the rule would enable them all to obtain
the social optimum and that a monitor would randomly audit one of the participants with a probability of 1/16 in each round (a realistic monitoring rate for a rural area). If a participant was found to have harvested more than the rule allowed, points were deducted from earnings. The expected costs of violating this rule were intended to induce an improvement of social efficiency. Larger group returns were achieved in the early rounds after the new rule was imposed. By the third round of the imposed rule, however, the gains were eroded. Self-interested behavior accompanied by imperfect monitoring led to much higher harvesting rates and greater group inefficiencies, even when compared to the nine rounds before the rule was imposed (see Cardenas et al., 2000). On the other hand, the groups that engaged in simple face-to-face communication increased individual and group earning substantially. Despite group communication leading only to nonbinding agreements (since all decisions continued to be made anonymously), these discussions did create and sustain, on average, more cooperative decisions by the participants leading to higher social efficiency and payoffs for all. Cardenas and coauthors explained the considerable variation observed in decisions and outcomes by the responses collected in a survey after the experiments were completed.

The purpose of the experiment described here is to build upon previous research, exploring how allowing for the institution of rules facilitates or interferes with effective group harvesting of resources. Unlike some studies (Bischoff, in press), 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 virtual world rather than interacting with sham participants.

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 & 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 & Baum, 2001), and realistic rules such as property rights based on spatial boundaries.

Experimental Design

We designed an experiment2 to test whether participants make the same pattern of decisions when a particular rule is chosen or is imposed, and whether participants behave the same under identical rule sets over time or learn new behavioral strategies on their own.

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 can collect tokens during three rounds, each of which lasts approximately four

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2 The instructions for the experiment and the survey are available upon request from the first author.
minutes; the duration of each round is not known to the participants. Each participant
harvests green tokens by moving a virtual avatar’s location on top of the tokens, 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 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.\(^3\)

\([\text{Figures 1 and 2}]\)

We began the experiment with 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

\(^3\) 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. While we know that participants, who participated in earlier experiments
related to common-pool resources (Ostrom, Gardner, & Walker, 1994), did understand the experiment,
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.
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 we
employed different treatments (Table 1).

[Table 1]

The first treatment was to continue with open access, and the second to impose a
private property rule. This private property rule included the demarcation of one-fifth of
the resource (see Figure 1) in the middle of each participant’s screen.\footnote{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.} 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 other rules in future
experiments. 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 cheater is
cought. 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, the second time 10 tokens, and each subsequent time the
participant is caught a penalty of 15 tokens is imposed.

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
like to 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 treat separately the groups where the private property rule is and is not chosen.

In the third round of the experiment, all 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 will 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. If the participants correctly anticipate the end of the round and harvest all the tokens just before the round ends, the earning could even be about 5 dollars higher.

Results
We performed a series of experiments from October 24, 2005 to November 4, 2005 in the Interdisciplinary Experimental Laboratory 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.

**Round 1**

Figure 3 shows that all groups depleted the renewable resource rapidly, although there was some variation. 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 only earned on average about one quarter of the potential payments. The participants had to watch the empty screen for the remaining time (on average about 4 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. 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 did vary both across the whole population of participants and within each group (Figure 4). To illustrate the variation within groups, the tokens harvested by each participant were normalized by the amount of tokens

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5 When we brought participants back to the laboratory after they had participated in one experiment and had them participate again, there was no significant difference in their behavior from the first time. We conclude that overharvesting is not a consequence of lack of understanding of the experimental environment.
collected by each group before the resource was depleted. The average share is necessarily 20%, 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). A higher variation 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 have harvested more when they all harvested more slowly. However, in this situation each participant experiences the temptation to get a higher share by increasing their own harvesting rate. Hence the dilemma this experiment presents to the participants.

[Figures 3, 4, and 5]

We analyzed whether participants in a group start to converge to the same rate of harvesting. We correlated the amount of tokens harvested within the first 30 seconds with the amount of tokens harvested by the rest of the group, and found no significant correlation. We did the same for the number of tokens harvested in the second 30 seconds, and again we found no significant relationship. Therefore, we reject the hypothesis that individual harvesting behavior is changing as a consequence of the behavior of others.

What are the attributes of the participants that affect their harvesting rate in round 1? Using the survey data we found that neither video game experience nor academic
major had an influence. Male participants, however, had a significantly higher share of the 5-person total earnings, 21.9 percent compared to female participants, 19.4 percent (one-way ANOVA, F(1,162)=21.07, p<0.0001). Another factor that correlates with higher shares is the size of the high school that a participant attended. The results of a regression analysis are reported in Table 2.

[Table 2]

Round 2

In round 2, there were four different treatments: open access (as with Round 1), private property rule imposed, and a vote for property rule (with two outcomes—property rule elected or not). When participants had the choice to invest in the private property rule, 46 of the 100 participants invested 50 tokens in making 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 (Figure 6).

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). 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 collected was 290 vs. 319 (One Way ANOVA, F(1,16)=1.22; p=0.29).
When the rule was not implemented, the number of tokens collected in the second round is not significantly different from the number collected in the first round. Restricting analysis only to data collected from groups that eventually chose not to adopt the rule in Round 2, the number of tokens collected per person was 182 in Round 1 and 183 in Round 2 (One way ANOVA, F(1,20)=0.002, p=0.97). The time until the last token collected was 86 seconds in both the first and second round (One way ANOVA, F(1,20)=0.005; p=0.95). When open access continued exogenously in Round 2, the average number of tokens collected per person was 189 in Round 1 and 185 in Round 2 (One way ANOVA, F(1,6)=0.034; p=0.86). The time until the last token collected was 85 seconds in Round 1 and 139 seconds in Round 2 (One Way ANOVA, F(1,6)=0.651 p=0.45). Chosen and imposed open access do not differ statistically in their number of tokens collected (One Way ANOVA, F(1,13)=0.11; p=0.735) or the duration of the round until the last token was collected (One Way ANOVA, F(1,13)=2.61; p=0.13).

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). When the private property rule was not implemented, those who invested in the rule change derived 5 tokens less, while non-investors 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 7 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.

[Figures 6 and 7]

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 group of participants invested in the rule change (Table 3). When the private property was imposed, we find a small effect of participants’ major; those studying participants where rational choice plays a prominent role (economics, accounting, business) derived more tokens.

[Table 3]

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 a statistically significant model. 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 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 sufficiently many others would invest in the rule change. When a participant invested in the rule change, but insufficiently many others did, 16 of the 17 participants indicated that they would invest again given a new opportunity.

Stealing behavior

When the private property rule is implemented, participants “steal” from other properties. We do not find a difference between imposed private property and chosen private property rules in terms 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 in the rule stole more tokens than those participants who did invest in the rule, 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 would earn an expected 0.5 token per token stolen when one has not been caught yet. When one has been caught once, the expected benefit of stealing an additional token is zero. When one has been 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 8 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 9), and therefore on average lost money by stealing additional tokens.

Where did the participants steal tokens? Figure 10 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 wealth imbalance, rather than retaliation, that drives stealing behavior.

**Table 4**

**Figures 8, 9, and 10**

**Round 3**

In Round 3, open access was used 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 (One Way ANOVA, F(1,20)=0.28, p=0.60 and One Way ANOVA, F(1,6)=0.07, p=0.80 for the chosen and imposed open access in Round 2, respectively). 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 than in Round 3 than Round 1 (1390 vs. 1002, One Way
ANOVA, 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. For Round 3 results we compare groups in which Round 2 included imposed or chosen property rights (One Way ANOVA, F(1,16)=0.50, p=0.49), and we also compared Round 3 results if Round 2 was open access, chosen or imposed (One Way ANOVA, F(1,13)=0.001, p=0.98). The same results hold for the number of seconds it took to collect the last token in Round 3.

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).

The number of tokens collected in Round 3 compared to Round 1 is lower when Round 2 was open access, but this difference is not statistically significant (One Way ANOVA, F(1,20)=0.28, p=0.61 for chosen open access; One Way ANOVA, F(1,6)=0.27, p=0.62 for imposed open access). The same results also hold for the time taken to collect the last token.

What affected the relative share of tokens collected in the third round? In Figure 11, 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 round compared to the “yes” voters. It appears that “yes” voters reduced their harvesting even when the rule was not implemented, which favored the “no” voters. “Yes” voters achieved a significantly higher token harvest 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.

[Figure 11]

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, as well as whether the participant invested in the rule change (Table 5). A major with a focus on monetary issues has a positive effect on the 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 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.

[Table 5]

Finally, we observe an increase in variance of relative shares in Round 3 compared to Round 1 when participants have experienced private property in 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 (0.038 vs 0.041 One Way ANOVA, \( F(1,28)=0.11, p=0.74 \)). This confirms the indication given in Figure 11 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, with the people who voted against the rule performing better than these people who voted for the rule.

**Discussion**

A novel, real-time, and spatially explicit renewable resource experiment was used to study the effects of rule change 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 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 affects the resource use. We found that about half of the participants were willing to invest on average 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 can see these investments as contributions to a threshold public good game with uncertainty, where the public good is the new property system and the threshold is more than 50% of the votes in favor, and uncertainty holds over the benefits of the private property regime.
Our result is 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 relatively over-contribute (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 did 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 between imposed and chosen institutional settings. This contradicts some earlier findings of Cardenas 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 caused by 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 free ride on the more
cooperative behavior of others, since 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 on the third round. Although experience with a more productive institutional rule (private property) leads to a change in behavior, we can not directly conclude that this experience leads to better results for the group.

The results indicate both surprising lack of spontaneous learning but also an influence of exposure to alternative strategies. On the one hand, for those groups that were never exposed to harvesting under property rights, there was no evidence that they spontaneously learned to limit their own harvesting rates. Even after experiencing the complete eradication of resources on 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. However, this transfer was far from complete. These groups did not perform nearly as well after the rule was lifted as they had performed while it was in effect. Furthermore, the 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 a private property rule may be neither 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 over-harvesting apparently led some participants to vote for the property right rule, and also to take more advantage of the property rights once instated. However, appreciating the nature of the game is not sufficient for efficient resource use, as was poignantly shown in the third round, in which participants who voted for the rule perform less well than participants who did not. At least in our paradigm, participants’ understanding must be united with the possibility for organization-building if robust and large improvements to group performance are 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 than when participants decided on this rule themselves. This contrasts with earlier results that imposing a sanctioning system does lead to different behavior than when participants decide on this rule themselves. Second, experience with an effective institutional arrangement may lead to more inequality when this institutional arrangement is removed.
References


Tables and figures

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

<table>
<thead>
<tr>
<th>Treatment (Groups)</th>
<th>Round 1</th>
<th>Rule investment</th>
<th>Round 2</th>
<th>Round 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>No private property (4)</td>
<td>Open access</td>
<td>n/a</td>
<td>Open access</td>
<td>Open access</td>
</tr>
<tr>
<td>Private property imposed</td>
<td>Open access</td>
<td>n/a</td>
<td>Private property</td>
<td>Open access</td>
</tr>
<tr>
<td>Private property chosen</td>
<td>Open access</td>
<td>&gt; 50%</td>
<td>Private property</td>
<td>Open access</td>
</tr>
<tr>
<td>Private property not chosen</td>
<td>Open access</td>
<td>&lt; 50%</td>
<td>Open access</td>
<td>Open access</td>
</tr>
</tbody>
</table>

Table 2: Statistics of a linear regressions. Year refers to college program (freshman=1 ... senior = 4). Major is 1 is monetary oriented majors like business, economics, accounting; 0 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.

<table>
<thead>
<tr>
<th></th>
<th>Fraction 1 (153 observations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.214 (18.9) ***</td>
</tr>
<tr>
<td>Year</td>
<td>-0.002 (0.78)</td>
</tr>
<tr>
<td>Major</td>
<td>0.004 (0.70)</td>
</tr>
<tr>
<td>Gender</td>
<td>-0.023 (3.46) ***</td>
</tr>
<tr>
<td>Ln(1+work)</td>
<td>-0.003 (1.40)</td>
</tr>
<tr>
<td>Ln(1+video)</td>
<td>-0.002 (0.52)</td>
</tr>
<tr>
<td>School</td>
<td>0.008 (1.91) *</td>
</tr>
<tr>
<td>R²</td>
<td>0.155</td>
</tr>
</tbody>
</table>

Table 3: Statistics of a 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.

<table>
<thead>
<tr>
<th></th>
<th>Elected rule Fraction 2 (42 observations)</th>
<th>Imposed rule Fraction 2 (44 observations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.146 (1.98) **</td>
<td>0.290 (3.64) ***</td>
</tr>
<tr>
<td>Fraction 1</td>
<td>0.173 (0.58)</td>
<td>-0.503 (1.52)</td>
</tr>
<tr>
<td>Year</td>
<td>-0.011 (1.354)</td>
<td>-0.001 (0.07)</td>
</tr>
<tr>
<td>Major</td>
<td>0.008 (0.47)</td>
<td>0.041 (1.72) *</td>
</tr>
<tr>
<td>Gender</td>
<td>0.006 (0.26)</td>
<td>-0.016 (0.65)</td>
</tr>
<tr>
<td>Invested</td>
<td>0.06 (3.095) ***</td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.234</td>
<td>0.139</td>
</tr>
</tbody>
</table>
Table 4: Statistics of a linear regression 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.

<table>
<thead>
<tr>
<th></th>
<th>Tokens stolen (invested private property) 45 observations</th>
<th>Tokens stolen (imposed private property) 45 observations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.16 (0.02)</td>
<td>10.1 (1.99)*</td>
</tr>
<tr>
<td>Invested in private property</td>
<td>0.79 (0.12)</td>
<td></td>
</tr>
<tr>
<td>Number of tokens stolen from own private property</td>
<td>0.22 (1.29)</td>
<td>-0.51 (0.37)</td>
</tr>
<tr>
<td>Average number of tokens of neighbors – average number of tokens on own property</td>
<td>0.002 (3.07)**</td>
<td>0.001 (2.7)**</td>
</tr>
<tr>
<td>R²</td>
<td>0.16</td>
<td>0.21</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th></th>
<th>Elected rule Fraction 3 (42 observations)</th>
<th>Imposed rule Fraction 3 (44 observations)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>0.221 (3.64) ***</td>
<td>0.044 (0.76)</td>
</tr>
<tr>
<td>Fraction 1</td>
<td>0.259 (1.097)</td>
<td>1.002 (4.68) ***</td>
</tr>
<tr>
<td>Fraction 2</td>
<td>-0.347 (2.69) **</td>
<td>-0.223 (2.24)**</td>
</tr>
<tr>
<td>Year</td>
<td>0.005 (0.72)</td>
<td>-0.008 (1.12)</td>
</tr>
<tr>
<td>Major</td>
<td>0.029 (2.059) **</td>
<td>0.029 (1.87)</td>
</tr>
<tr>
<td>Gender</td>
<td>-0.003 (-0.16)</td>
<td>0.011 (0.70)</td>
</tr>
<tr>
<td>Invested</td>
<td>-0.042 (-2.69) **</td>
<td></td>
</tr>
<tr>
<td>R²</td>
<td>0.459</td>
<td>0.501</td>
</tr>
</tbody>
</table>
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.
Figure 2: Four snapshots of two types of participants in a hypothetical situation of a 5x5 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.
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.
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 include a linear regression (tokens=627.8+7258*standard variation) with $R^2 = 0.49$ and a significant correlation between both axes ($p<0.00001$).
Figure 6: Distribution of number participants who invested in the rule change across groups. Black represent yes votes, and white represent no votes.
Figure 7: Number of tokens collected in round 2 vs. average resource size on their individual plot, for each participant in experiments with private properties.
Figure 8: Distribution of the number of tokens participants collected from other properties.
Figure 9: Distribution of the number of times participants were caught stealing tokens.
Figure 10: Distribution of the distance between stolen tokens and a participant’s property.
Figure 11: 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 were allowed to invest in rule change in round 2.