The influence of collective property rights on grazing management in a semi-arid region

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In this study, common-pool resource experiments were carried out to analyze the efficiency of two simple, imperfectly enforced collective property-rights allocation rules. The design of the property-rights regimes in our experiment is based on both informal real-world arrangements practiced in the communal areas in our southern Namibian study site and the procedure used by the Namibian government, where communal farmers are granted access to resettlement farms according to their prior use of the commons. Our results suggest that in the short run the introduction of collective property rights increases the economic returns and has positive ecological effects, but that the unequal distribution stimulates inequality aversion, which diminishes the positive effect in the long run if the rules are only imperfectly enforced. We also find evidence for spiteful behavior, as a substantial fraction of subjects destroy the others' grazing area, even though this has negative payoff consequences for the person who behaves spitefully.

Keywords: field experiment; common-pool resource; property rights; rule following behavior; Namibia

Dans cette étude, des expériences sur les biens communs ont été menées pour analyser l'efficacité de deux simples règles, imposées de manière imparfaite, et concernant l'allocation des droits réels collectifs. Dans notre expérience, la conception des régimes du droit réel se base à la fois sur les arrangements informels pratiqués en réalité dans les zones communes du site du sud de la Namibie, utilisé dans notre étude, et sur la procédure utilisée par le gouvernement namibien autorisant les fermiers communaux à réinstaller leur ferme sur des terres collectives qu'ils ont auparavant exploitées. Nos résultats suggèrent que, sur le court terme, l'introduction des droits des biens communs augmente les rendements économiques avec effets positifs sur l'environnement. Par contre, la distribution inégale attise l'aversion pour l'inégalité, qui affaiblit, sur le long terme, l'effet positif lorsque les règles ne sont imposées qu'imparfaitement. On note également des attitudes rancunières, avec un nombre important d'individus détruisant les pâturages de leurs voisins, quand bien

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même cela entraînera des gains négatifs pour les personnes se comportant de manière mesquine.

Mots-clés : *expérience sur le terrain ; bien commun ; droits réels ; comportement face aux règles à suivre ; Namibie*

1. Introduction

Ever since the publication of Garrett Hardin's landmark 1968 article it has been argued that privatization of common-pool resources is the first-best solution to prevent overgrazing and increase productivity where resources are scarce. Many economists argue that private property rights increase security and thus enhance investment incentives (e.g. Demsetz, 1967; De Alessi, 1980; Binswanger et al., 1995). However, this proposition has been challenged on the grounds that (i) common-pool resource management does not inevitably end in overexploitation and resource degradation as indigenous management systems are flexible enough to regulate access and to cope with increasing land scarcity (Ostrom, 1990; Platteau, 1996), (ii) state intervention in land matters is often more harmful than helpful, and (iii) empirical evidence on the relation of private property rights to efficiency is ambiguous (Migot-Adholla et al., 1994; Besley, 1995; Brasselle et al., 2002; Jacoby et al., 2002).

Apart from these concerns about the superiority per se of private property rights regimes over other resource management regimes, some resource systems have characteristics that make privatization difficult or even impossible. For example, collectively owned rangelands in semi-arid areas have an insurance function against spatially uneven rainfall. In our study region, farmers in areas affected by too little rain are allowed to move their animals to neighboring areas (after having asked for permission) and hence do not automatically risk losing their herds in times of drought. On the other hand, if semi-arid rangelands were privatized into plots that are too small, landholders who received too little rain in one season could be forced to reduce their herd drastically, which in turn would threaten their livelihood. Furthermore, the allotment of semi-arid rangelands could create a 'tragedy of the anticommons', where each individual has a right to a resource which is, however, too small to farm efficiently (Heller, 1998). The problems of anticommons and resource system specifics might explain the interesting finding of Mwangi (2007), who reports that the Maasai started to recombine their resources into larger plots after the once collectively managed rangelands were privatized. Thus, privatization is not necessarily the best option per se.

According to Platteau (2000) there are two distinct stages in the debate about land rights. The first is about how customary land gets individually appropriated (use rights) and the second about whether property rights get individualized or not (transfer rights). Currently, we are observing gradual transformation of the use rights in our study area, where increasing market integration and scarcity of grazing land lead to tendencies to bring the traditionally open pasture land under private control around permanent water points. Such informal property rights are already present since farmers have inherited from their parents de facto rights to use a specific area. This allocation is mostly binding, and enforced either physically or through social pressure. However, monitoring is extremely difficult in vast areas, boundaries are fuzzy, and thus it is still possible to free-ride on another farmer's area without being detected.[2] We try to simulate the behavioral implication of this situation with our experiment

[2] Land allocation in our study site is in the hands of the traditional authority (Keulder, 1997: 32), and outsiders

by investigating the efficiency of two different collective property rights rules that diminish an existing coordination problem among farmers, but create unequal access to the pasture. Our study uses a field 'laboratory' setting based on a dynamic common-pool resource experiment[3] initially developed by Cardenas et al. (2008). We confront communal pastoralists from southern Namibia with a baseline setting where five farmers have to manage a (hypothetical) rangeland around their village. The rangeland consists of two areas, and according to previous use each grazing area can be in either good or bad condition, leading to high or low payoffs, respectively. The inclusion of two grazing areas in the experimental set-up allows us to test the impact that collective property rights have on individual earnings and resource availability. In the open-access situation (stage 1), when nobody is assigned to a specific pasture, participants face a cooperation (what intensity to graze) and coordination (what area to choose) problem.

Assigning property rights always has distributional implications which might stimulate behavioral responses. In the first treatment we assign property rights to those two farmers who behaved most selfishly (i.e. who exploited the resource most) in the open-access situation on a single pasture where resources are abundant (i.e. there are no externalities, even if they apply the highest intensity), while leaving the other pasture with scarce resources for the three remaining farmers. This *proportional division* of the resource according to prior use rates has been shown to be Pareto-dominant, as nobody's interest will be hurt in such a situation (Roemer, 1989).[4] The other treatment reverses the situation: we assign the property rights over abundant resources to those two farmers who were most cooperative, and leave the most selfish players on the neighboring grazing area with rivalry in consumption. As in reality, property rights are imperfectly enforced. However, when everybody obeys the rules, both treatments solve the coordination problem and the cooperation problem disappears, at least for those two farmers assigned to the area where resources are abundant. At the same time both treatments create an uneven distribution of land among players, which might activate social responses such as envy or guilt, as posited by the Fehr-Schmidt Fairness Model (Fehr & Schmidt, 1999). The classification of players according to their behavior in the open-access situation allows us to test whether revealed social preferences are consistent across the course of the game and, more importantly, to investigate the impact of heterogeneous social preferences on the efficiency of property rights regimes.

Our analysis is also relevant to the ongoing land reform process in Namibia and South Africa, where the government offers communal farmers land which will then be their formal 'group' property. In Namibia, farmers who own big herds are usually granted access to private farms, while those with small herds remain on the commons. In everyday life, however, monitoring is imperfect, and it is frequently reported that farmers who obtained a private farm still graze their animals on the commons, and only move their herd to their private farm when grazing

are prevented from entering the commons so that no open-access situation emerges. The traditional authority permits farmers to settle in an area when enough grazing is available. In case a group of farmers decides to rotate and spare part of the land, there is obviously grazing land available and traditional authorities could re-allocate the spare land. However, with the Water Reform in Namibia (Republic of Namibia, 2004), the local Water Point Associations have the right to regulate access to water, which is intricately linked to the access to land. Thus, the new regulations give more power to the local people to manage their resources, which is reflected in the perception of four fifths of farmers from our study site that somebody who wants to settle in an area has to ask the respective residents first (Falk, 2008).

[3] According to the terminology proposed by Harrison & List (2004: 1014), our experiments are *framed field experiments*.

[4] However, Platteau (2000) gives some reason why this rule is seldom applied in real life: first, there is no reliable information on past use (which we have in our experiment); and second, unequal access rights reflect an implicit community hierarchy in social status.

gets scarcer on the communal pastures (personal communication, Anton Losper, Extension Officer, Ministry of Agriculture, Water and Forestry, southern Namibia, 5 October 2009). Our household survey reveals that 34% of respondents (41 out of 120) have heard of former communal farmers who were granted access to private farms still grazing their animals on the commons after the rainy season. The vast majority of these respondents saw this behavior as unfair and corrupt. By using the village commons the resettled farmers aggravate the problems for the majority of poor people who rely on the commons for subsistence farming. Thus, although property rights are assigned, the efficiency enhancing effect is not guaranteed since people do not always obey the rules. With our experiment we further test whether trespassing happens and, if so, whether repeated sanctions and monitoring alters behavior toward less trespassing.

The paper is structured as follows: Section 2 presents the experimental design, the treatments with derived hypotheses (see also Appendix A for more details)[5] and the description of participants. Section 3 presents the results and in Section 4 we summarize and conclude.

2. The experiment

2.1 Experimental design

A limitation to the external validity of the standard common-pool model (e.g. Ostrom et al., 1992; Cardenas, 2003; Velez et al., 2009) is the artificiality imposed by the oversimplified situation of choosing stock numbers only according to a repeated one-shot Prisoners' Dilemma design. To increase external validity, Cardenas et al. (2008) recently developed an experimental set-up with features of path dependency of previous use, spatial variability and non-linear payoffs. Their design makes it possible to focus on the decision-making process in complex environmental settings. In earlier common-pool resource games, resource conditions are usually static, i.e. resource availability is the same in each round irrespective of the extraction rates in previous rounds. This assumption, however, ignores the complex ecological relationship between unpredictable and spatially variable rainfall, drought periods, plant growth and grazing management which is characteristic of our semi-arid study area. Previous stocking rates as well as rainfall have a strong influence on current resource availability. We consider this in our experimental design by introducing the possibility of (temporary) resource degradation when stocking rates exceed a certain threshold.[6]

Only a few experimental studies on common-pool resource management consider possible resource destruction where there is overuse (Walker & Gardner, 1992; Muller & Vickers, 1996; Bischoff, 2007). However, unlike these studies, we allow for resource recovery and directly link economic returns to resource availability. Since degradation causes a decline in productivity and hence lowers the profits even if the herd size remains unchanged, we pay fewer tokens for the same grazing intensity (i.e. stocking rate) where the grazing quality is

[5] Appendix A contains the derivation of the game equilibria. Appendix B presents supplementary analyses and descriptive statistics of the participants. Appendix C presents the experimental protocol. Appendices B and C can be obtained from the corresponding author on request.

[6] In our experiment only stocking rates affect resource availability, though recent ecological research suggests that natural events such as low rainfall or prolonged droughts can have a much stronger effect on resource availability than stocking rates (Ward et al., 1998; Ward & Ngairorue 2000). One way to include natural events in the experimental design would have been the consideration of random destruction (e.g. Walker & Gardner, 1992).

low rather than high. Furthermore, participants choose not only a level of extraction from the grazing resource but also the location (A or B) where they want to graze their livestock. This is a more realistic feature and necessary in order to define spatial property rights and thus to exclude people from resource use in a certain area. We decided to play the experiment without communication in order to have a benchmark case of no communication and anonymity and, most importantly, because of the low population density in our study site. In southern Namibia communal farmers spend most of their time on very small livestock posts, which are usually occupied by one or two extended families and are widely scattered in the territory. The posts are often several kilometers away from each other, which limits the possibility of frequent communication among farmers who live on different livestock posts but use the same pasture.

An experimental session consists of five participants and lasts for 20 rounds. The composition of groups remained unchanged throughout the session (fixed matching). In each round, each participant chooses a grazing intensity of 0, 1 or 2 and decides whether to graze on area A or B. The higher the grazing intensity, the higher the return. However, according to the payoff table (Table 1), returns to grazing depend not only on the intensity of farming but also on the condition of the rangeland, which can be good or bad. For example, an intensity of 1 yields seven tokens when the chosen grazing land is in good condition, but only one token where the grazing availability is low. A pasture's resource availability depends on the aggregate group intensity invested in the previous round. Since the maximum intensity that one single player can choose is 2, the aggregate intensity in the two sites ranges between 0 and 10. Where the group effort exceeds the carrying capacity of five in one location, the grazing availability of that site moves from high to low. To recover to a state with high stock level, a group intensity of maximally 1 unit has to be invested in that site for two successive rounds.

The resource can be either in good condition (H) or in bad condition, with two more rounds to recover (L_2) or one more round to recover (L_1). Thus, there are six possible combinations a group might be in:

- HH: both areas in high condition.
- HL_1: one area in high condition, the other low but already recovered one round.
- HL_2: one area in high condition, the other low and needing two rounds to recover.
- L_1L_1: both areas in low condition and needing one round to recover.
- L_2L_1: one area in low condition and needing two rounds to recover, the other needing one round.
- L_2L_2: both areas in low condition and needing two rounds to recover.

Table 1: Payoff table for the experiments

Intensity / *Condition*	0	1	2
GOOD	0	7	8
BAD	0	1	2

Altogether, we ran 12 sessions, each consisting of five participants randomly chosen from a pool of possible participants recruited by word-of-mouth advertisement and public announcements at meetings of various organizations. At the beginning of each session a local field assistant read the instructions aloud and two or three practice rounds were then played.[7] We also handed out a short quiz consisting of seven questions, to test whether the participants understood the structure of the game. When the participants had completed the quiz, the correct answers were announced and last questions clarified. Before the experiments started, participants were scattered across the room to make sure that nobody could see the others' decisions.

A session was subdivided into two stages, each lasting 10 rounds. At the beginning of each stage, both grazing areas were in good condition (resource scenario HH). In each round the participants received a decision card where they had to write down their player number, the grazing intensity (0, 1 or 2) and the location (A or B) they wanted to graze in. The decisions were made in private and it was promised that individual decisions would never be disclosed to the other players. Communication between the participants was impossible during the game. When all had made their decisions, the experimenter collected the decision cards and announced the aggregate group intensity for each grazing location and the resulting condition of the resource for the following round. In the first stage (rounds 1–10), equivalent to an open-access situation, no rules were in place. In the second stage (rounds 11–20), we randomly implemented two simple property-rights sorting treatments, either *property rights for selfish* (PRS) farmers or *property rights for cooperative* (PRC) farmers, which are described in the next subsection. We used a between-subject design. Each treatment was tested within six sessions. After the final round had been played, the participants were asked to complete a short questionnaire on socio-demographic characteristics.

We first examine the *equilibrium behavior during the first 10 rounds*, when no rules were in place and the game corresponded to an open-access situation. According to classical game theory for finitely repeated non-cooperative games, we would expect subjects to maximize their own monetary payoff and not to have other-regarding preferences. In our experimental setting, the single dominant strategy is choosing an intensity of 2 in each round, since this choice yields the highest individual payoff irrespective of the condition of the resource. We therefore expect the degradation of one grazing area immediately after the initial round, ending up with one location in good and the other in bad condition (HL_2) at the beginning of round 2. Since intensities applied on good grazing areas yield the highest return, all will choose the remaining location in good quality, resulting in a situation where both grazing areas' availability is low (L_2L_1) at the beginning of round 3. The area choices now depend on whether subjects are myopic or deliberate egoists. The details of their choices and the

[7] The experimental protocol was presented in Afrikaans. The protocol is available in Appendices B and C, obtainable from the corresponding author.

subsequent equilibria are discussed in detail in Appendix A. The myopic players realize that both grazing areas are of low quality, such that it does not matter which one they choose. This leads to the almost certain continuous degradation of both grazing areas. The deliberately selfish players recognize that the area L_1 can recover faster to high quality than the L_2 area. They will therefore choose L_2 and a kind of rotation system automatically emerges which will contain one high quality grazing area every second round. In the myopic selfishness equilibrium the total group earnings for rounds 1 to 10 are 160. In the deliberate selfishness equilibrium the total group earnings for rounds 1 to 10 are 280.

In contrast to these non-cooperative equilibria, the social optimum, i.e. the maximum total earnings if everyone were playing cooperatively and individuals could coordinate their actions, gives a total group earning of 390 for rounds 1 to 10. This can be achieved if four players choose intensity 2 and the remaining player chooses intensity 1 and the area choices are coordinated such that the grazing intensities never exceed five on any area. However, this equilibrium cannot be reached because in our experiments the participants could not communicate and therefore could not coordinate their actions. The cooperative equilibrium without communication is derived in Appendix A. In this equilibrium, everyone chooses intensity 1 on the good area in the situation HL_2. Otherwise, intensity 2 on a good area is chosen. This strategy leads to a cycle HH → HL_2 → HL_1 → L_2H etc., i.e. the game cycles between the situations HL_1 and HL_2. In this way one good grazing area is maintained in each round, leading to total group earnings of 375.

From the detailed derivations in Appendix A, Hypothesis 1 with testable implications follows.

Hypothesis 1 (Open-access stage, rounds 1 to 10):

a) In the *myopic selfishness equilibrium* individuals always choose intensity 2; when the grazing situation is L_1L_2, they choose the area L_2 with probability 0.5; the probability of finding a good grazing area in rounds 3 to 10 is almost zero; and the total group earnings for rounds 1 to 10 are 160.

b) In the *deliberate selfishness equilibrium* individuals always choose intensity 2; when the grazing situation is L_1L_2, they choose the area L_2 with probability one; in every second round one grazing area is of high quality; and the total group earnings for rounds 1 to 10 are 280.

c) In the *cooperative without communication equilibrium* individuals choose intensity 1 when the grazing situation is HL_2; the probability of finding at least one good grazing area in every round is 1; and the total group earnings for rounds 1 to 10 are 375.

2.2 Property rights treatments and predictions

After round 10, property rights were introduced for the remaining 10 rounds. Half of the groups were allocated randomly to either a PRS or a PRC farmers treatment, as explained in Section 2.1. above. (We use the labels PRS and PRC in the following, but this framing was unknown to the subjects, who also did not know that different rules were implemented.) In both property rights sorting treatments, two players were allocated to grazing area A and the remaining three to area B. The treatments differ only with respect to the player 'types' allocated to area A and B. We distinguish between more 'selfish' and more 'cooperative' player types depending on their relative performance in rounds 1 to 10: those members of a group who applied the highest cumulated intensity in the first 10 rounds were classified as 'selfish' players and, consequently, those who chose the lowest cumulated intensity in stage 1 were referred to as 'cooperative'.[8] In the PRS treatment, the two farmers who chose the highest cumulated intensity in the first stage obtained the property right to jointly use grazing area A from rounds 11 to 20, while the three lowest intensity farmers had to graze on location B. In the PRC treatment, the two most cooperative farmers, i.e. those with the lowest cumulated intensity in stage 1, were allocated to location A, and the three highest intensity farmers to location B. Subjects were informed about their designated location secretly by being given a blue card marked with an A or B. Therefore, every player only knew his or her own location and the number of other players sharing the same one, but not who these other players were. The property rights rules were imperfectly enforced by a random monitoring system with an audit probability of 20%. In each round, irrespective of whether a participant trespassed or not, we randomly drew one of the five player numbers and announced this number, but did not report whether the player in question deviated from the rule. Where the monitored person trespassed, the tokens earned in that round were subtracted.

With our treatments, we aim to test the efficiency of existing informal use rights in the communal areas, which are similar to the Namibian Government's formal procedure for granting farmers access to resettlement farms. We study whether collective property arrangements are beneficial compared to an uncoordinated open-access situation, i.e. whether subjects are able to improve resource availability and thus increase returns from grazing. We are further interested in how social preferences influence cooperation and rule following behavior.

We now examine the *equilibrium behavior during the rounds 11 to 20*, when the property rights rules have been put in place. The rule is the same for the PRS and PRC treatments, only the selection of the players is different. The details of the equilibria are again given in Appendix A. First we examine the uncooperative equilibrium. While we had distinguished between a *myopic selfishness* and *deliberate selfishness* equilibrium in the first stage of the game, after the introduction of the penalty rules there is only one single uncooperative equilibrium because everyone remains on the assigned area when both areas are of low quality.[9] From round 13 onwards, all areas will be of low quality and the total expected group earnings for rounds 11 to 20 are only 155.2.

Regarding cooperative behavior, we examine three different equilibria (see Appendix A). First, we could imagine that that all players cooperate, i.e. those assigned to area A and those to area B. Second, we can examine what happens if only those of either area A or area B cooperate (i.e. aim for highest social payout), while the players assigned to the other area are uncooperative. Third, in the fully cooperative equilibrium, we imagine the area A players always choose intensity 2 on their area and the area B players always choose intensity 1 on theirs. Thus neither of the grazing areas ever becomes degraded. In the second type of equilibrium, partly cooperative and partly uncooperative, if the area A players are selfish and the area B players cooperative, the result is identical to the fully cooperative equilibrium: the area A players always choose intensity 2 on their area and the area B players remain on their area and apply intensity 1. Hence, we cannot test empirically between the two different

[8] Even though the correlation between the cumulated individual intensity and the cumulated individual earning in round 10 was positive and high for both treatments (PRS: 0.76, p-value: 0.000; PRC: 0.66, p-value: 0.000), participants typed as 'selfish' and thus allocated to grazing area A (B) in the PRS (PRC) treatment did not necessarily yield the highest return in the first stage.

[9] The expected return from trespassing to the prohibited grazing area is only 1.6 tokens compared to 2 tokens if subjects adhere to the rule.

equilibria. On the other hand, if in the second type of equilibrium the area A players are cooperative and the area B players selfish, then we see a difference: the three players on area B always choose intensity 2 on the higher quality area, and the area A players take the choices of the B players as given and basically follow them in order to let one of the grazing areas rest. From the detailed derivations in Appendix A we derive the following hypothesis:

Hypothesis 2 (Property rights stage, rounds 11 to 20):

a) In the *uncooperative equilibrium* individuals always choose intensity 2; the probability of finding a good grazing area in rounds 13 to 20 is 0; and the total group earnings for rounds 11 to 20 are 155.2.

b) In the *cooperative without communication equilibrium* every player chooses the assigned area; area A players always choose intensity 2, area B players always choose intensity 1; in every round both grazing areas are always of high quality; and the total group earnings for rounds 11 to 20 are 370.

c) The *partly cooperative partly uncooperative equilibrium where area A players are selfish and area B players cooperative* is identical to the fully cooperative equilibrium (without communication).

d) In the *partly cooperative partly uncooperative equilibrium where area A players are cooperative and area B players selfish* the area B players always choose intensity 2; in the situations HL_1 or HL_2 they choose area A, i.e. they trespass if their grazing area is degraded,[10] otherwise they always graze on area B; the area A players react as follows: in the situation HH they choose intensity 2 on area A, in the situation HL_2 they choose intensity 2 on area A, in the situation L_1L_2 they choose intensity 2 on area B, in the situation L_2L_1 they choose intensity 2 on area B; from round 12 onwards the probability of finding at least one good grazing area is 0.33; and the total group earnings for rounds 11 to 20 are 200.8.

We can test Hypothesis 2 with respect to the data observed in rounds 11 to 20. However, because the treatment rules are assigned randomly, we can go one step further: if it were true that each player is either fully cooperative or fully uncooperative, we would expect players to reveal their type during sessions 1 to 10. In this case, we would expect that in the PRS sessions the area A players are selfish while the area B players are cooperative. At the same time, in the PRC sessions the area A players behave cooperatively while the area B players are selfish in stage 2.

Hypothesis 3 (PRS and PRC property rights):

If some players are cooperative and others uncooperative and if these two types are revealed by observed behavior we would expect a) that in the PRS sessions, the equilibrium of Hypothesis 2-c is observed, whereas we expect b) that in the PRC sessions, the equilibrium of Hypothesis 2-d is observed.

There is one caveat to Hypothesis 3: in order to be true, in the PRS sessions there should be two selfish farmers and three cooperative farmers and in the PRC sessions there should be three selfish farmers and two cooperative farmers. This, however, is impossible since the groups were assigned the PRS or the PRC rules randomly. We therefore test Hypothesis 3 but

[10] They trespass because the expected return from rule deviation in such a situation is 6.4 tokens compared to 2 units if they adhere to the rule and graze on their predefined (low-quality) grazing area.

also provide a more general discussion of the differences between the PRS and PRC sessions: generally we would expect that the earnings and the number of good grazing areas are clearly higher in the PRS than in the PRC session (as is clear from Hypothesis 2). In the PRS treatment, the two most aggressive players are on area A and can choose the highest intensity without degradation, whereas the three least aggressive players share the area B and maintain good quality by choosing intensity 1 only. If the latter were to trespass to area A, in the next round the aggressive area A players would trespass to area B since their own area had become degraded. Then both areas are degraded. Hence, the area B players have nothing to gain by trespassing (at least with respect to absolute earnings). Hence, in the PRS sessions we expect that everyone remains on his area, i.e. no trespassing should ever occur.

In the PRC sessions, on the other hand, the three aggressive players now share area B. Continuing with their previous behavior, they will immediately destroy area B and then move to area A, which will then also be destroyed. The other two least aggressive players basically follow the other three in order to allow one area to recover. Hence, in the PRS sessions we expect frequent trespassing, and that from round 12 onwards almost all players choose the same area. (Hence this is different from PRC sessions, where about half of the players choose area A and the other half area B.)

2.3 The participants

The experiments were carried out in small villages in the communal area of the Karasburg municipality (referred to as the Dreihuk area) in southern Namibia. The area lies in a semi-arid biome, characterized by low rainfall and poor soils that are only suitable for livestock production. Formal employment opportunities are rare and the majority of the population depends on livestock-keeping on a subsistence basis (Republic of Namibia, 2001). Livestock is kept on commonly managed grazing land. The participants are thus familiar with the management of common-pool resources. The game was administered with 60 subjects (see Appendix B.1 for statistical summary of participants). Of these 60, 45 owned livestock, and more than a third said livestock-keeping was their main economic activity. Only seven of the 60 had a permanent job, eight were working occasionally, and 23 were either unemployed or retired. The average monthly cash income per capita was N$315.[11] Slightly more than half of our sample were women (32 women and 28 men) and the education level was relatively high, with 9.2 years of schooling on average, ranging from 2 to 12 years.[12] Differences in socio-demographic variables between the randomly implemented treatments are all insignificant. With respect to 'player types', we found that those classified as 'cooperative' had significantly larger household sizes and less household income than selfish player types. Moreover, cooperative players significantly more often stated ex post that the game was very close to a real world scenario of grazing management.[13] At the sessions' end the participants were paid according to their total payoff yielded during the experiment. Individual earnings ranged from N$11.75 to N$38.75 with an average of N$26.30. Additionally, everybody received a participation fee of N$15. Paying a compensation fee is necessary to cover subjects' opportunity costs (Parkhurst et al., 2004), and to mitigate the problem of selection

[11] One Namibian dollar (N$) was about 13 US cents when we undertook the experiments in July 2008. A typical wage laborer earns N$30–50 a day.

[12] These and other socio-demographic characteristics are presented in Table B.1 in the appendices obtainable from the corresponding author.

[13] The regression of cumulated intensity of stage 1 on demographic variables is obtainable from the corresponding author.

bias, which could arise when only persons who are interested in experiments about grazing would participate.

3. Results

In this section we test the hypotheses developed in Section 2 and analyze the impact of the property rights treatments on grazing management. We first evaluate the overall treatment effect, by comparing grazing availability and individual earnings between stage 1 and stage 2. Here we also test our first hypotheses 1-a, 1-b and 1-c. Next, in Section 3.2, we compare the two property rights treatments, and in Section 3.3 we examine differences between player types and treatments regarding intensity choices, and individual earnings. In Section 3.3 we test both Hypotheses 2 and 3. While Hypothesis 2 takes the total sample from rounds 11–20 into account, Hypothesis 3 looks at either PRS (Hypothesis 3-a) or PRC treatment (Hypothesis 3-b). Lastly, Section 3.4 analyzes rule following behavior.

3.1 Pre-treatment behavior

In contrast to our first Hypothesis 1-a and 1-b, only about one third of the subjects chose the highest intensity of 2 units in the open-access stage of the experiments, while the majority (47%) grazed with intensity 1. This deviation from purely self-interested Nash behavior has been reported in many related studies (Ostrom et al., 1992; Velez et al., 2009), and is usually explained by the existence of other-regarding preferences (e.g. Fehr & Schmidt, 1999; Bolton & Ockenfels, 2000), such as altruism, inequity aversion and reciprocity; or by incomplete information about the players' types (Kreps et al., 1982). Concerning Hypotheses 1-a and 1-b, we observe that in stage 1 a mean intensity of 1.14 is applied, which is significantly different from 2 (n=600; t= 29.3; p=0.000). In the situation L_1L_2, the intensity 0 is chosen in 36% of all cases (n=90), which implies that players do not randomly vary between L_1 and L_2, nor do they always play L_2. However, if we omit the cases where players applied zero intensity we find that in 52% of all cases they play the better grazing area (L_1), i.e. the one that can recover sooner. Thus, if anything this points to a very large proportion of myopic players in our experiment (not necessary selfish players as discussed below). In contrast to Hypothesis 1-a, for none of the groups do we observe a situation where participants face low resource availability in both pastures for the entire course of the open-access stage: the mean number of good grazing areas per group from rounds 3–10 (12 groups and 8 rounds) is highly significantly different from zero (n=96; t=13.1; p=0.000). Nor do subjects apply a rotation system, where in every second round (between round 3 and 10) only one grazing area is good and the others are bad (Hypothesis 1-b). Otherwise the mean number of good grazing per round should be equal to 0.5 from round 3 onwards, which can also be rejected (n=96; t=6.8; p=0.000). Lastly, average group earnings are 239, and thus above the 160 points predicted by the myopic solution (n=12; t=5.05; p=0.000) and below the 280 predicted by the deliberately selfish solution (n=12; t=-2.6; p=0.024). We thus reject Hypotheses 1-a and 1-b.

If players instead were cooperative but unable to communicate (Hypothesis 1-c) they would choose an intensity of 1 if the grazing situation was HL_2 (or HL_1). We can reject this prediction for the situation HL_2 (n=155; t=2.04; p=0.04) although the mean is 1.11 and only slightly above the predicted mean intensity of 1. On the other hand, we cannot reject the hypothesis for the situation HL_1 (n=65; t=1.45; p=0.15) where players play an average intensity of 1.13.[14] We also cannot reject the one-sided test that the number of good grazing areas per round is smaller than one since the average number of good grazing areas per round is 1.18. Lastly, average group earnings amount to 239 tokens, and are thus below the 375 points predicted by the cooperative solution (n=12; t=-8.60; p=0.000). To sum up, we cannot reject all the auxiliary hypotheses of our Hypothesis 1-c and so we conclude that, if anything, a large portion of players are cooperative but perhaps too challenged by the coordination problem posed by the experimental design and therefore they do not reach the predicted high outcome.

Figure 1 shows the percentage of good pastures per round over the course of the game, separated by the treatments. The number of good pastures indicates resource availability and serves as a measure for rule efficiency. It is clear that there is a significant large difference between the treatments in the open-access situation from rounds 1 to 10 (Mann-Whitney test: Z=3.908, p<0.01): groups that were assigned to the PRS treatment (the line with squares) maintain on average more pastures in high quality (about 71% compared to 48%) than their counterparts assigned to the PRC treatment (the line with triangles) even before the introduction of the treatments. Interestingly, while mean intensities do not differ between the treatments if considering individual intensity choices across *all* six resource scenarios (Z=0.47, p=0.67), they are significantly higher in the PRC treatment if we restrict our analysis to intensity choices made in situations where at least one pasture was in good condition (Z=2.787, p<0.01), i.e. in the situations HH, HL_2 and HL_1, only.[15] This suggests that treatment differences in stage 1 were not due to coordination failures among subjects assigned to the PRC treatment but rather to a lack of cooperation among them in situations of relatively high resource availability.

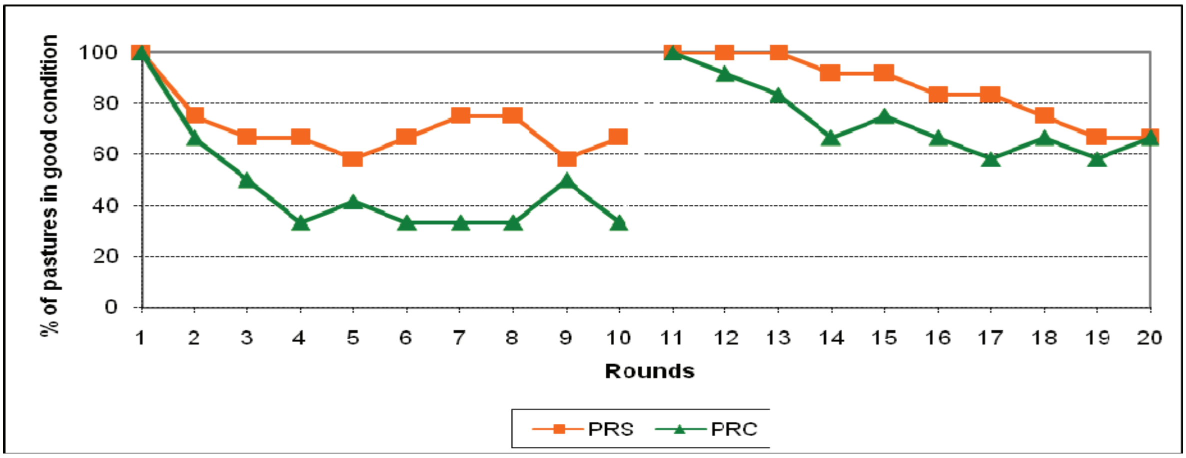

Figure 1: Average grazing quality over the course of the game, separated by stage and treatment

[14] The average intensities vary substantially among different resource scenarios. For example, if groups face situations of bad resource condition in both grazing areas (L_1L_1, L_2L_2 or L_1L_2), group members apply about 0.68 units, while the average intensity is 1.41 if both pastures are in good condition (HH). Thus, players adjust their grazing intensity according to the ecological situation they face.

[15] Across all six resource scenarios, the average intensities are 1.13 and 1.16 units in the PRS and PRC treatments respectively, while they amount to 1.19 (PRS) and 1.38 (PRC) in HH, HL_1 and HL_2. We do not observe a significant difference if we consider all resource scenarios since PRC groups more frequently face a situation of low resource availability in both pastures (in 17% of all cases compared to about 6% in PRS), i.e. situations where low intensities are required to reach resource recovery.

At the first glance, one may assume that the substantial difference is due to sample selection bias. However, the assignment of property rights was completely random, as was the recruitment of participants. Moreover, regressions of socio-demographic variables on grazing quality do not show any significant difference between the two treatments. Thus, the treatment difference cannot be attributed to sample heterogeneity, nor is it due to different group compositions with respect to the proportion of female participants or farmers in a session, for which we controlled as well. Presumably, the treatment difference is an unfortunate coincidence owing to the relative small sample size of our study. Obviously, this coincidence demands control for the observed differences in the first 10 rounds. More informative is within-treatment comparison between the open-access and treatment stage (see e.g. Table 2). As long as we restrict our analysis to subjects' behavior under the same resource condition (i.e. it is possible to compare intensity choices or earnings of A-players between treatments for the situation HH, or L_1L_1), it is also still possible to make a sound statistical inference.

3.2 Treatment effects

In round 11, we assigned the collective property rights treatments that were in place for the remaining 10 rounds of stage 2. The introduction of property rights increases individual intensities significantly, amounting on average to 1.33 units in the treatment stage compared to about 1.14 in the open-access situation (significant difference on 1% level, two-sided test). Directing attention to intensity choices made in stage 2, after the property rights treatments had been implemented, shows that all player types but the B-players in the PRC treatment (i.e. the three most selfish ones in the first stage) apply significantly higher intensities than in the first 10 rounds. Despite higher grazing intensities, the introduction of property rights has a significant positive impact on resource availability. Though resource degradation still happens in the treatment stage, about 80% of all grazing areas on average remain in good condition during rounds 11 to 20, compared to about 59% in the open-access stage. Moreover, a separate analysis for each property rights treatment further reveals that *each* treatment leads to a significantly higher number of grazing areas in good condition compared to the open-access situation in stage 1. In PRS, groups maintain on average 86% of all pastures in good condition compared to 71% in stage 1 ($Z=2.4$, $p=0.02$); and PRC groups enjoy good grazing areas in 73.5% of all cases compared to 48% in the first 10 rounds ($Z=3.6$, $p<0.01$). This suggests that the coordination contrivance provided by the allotment of group property rights is successful. However, as Figure 1 shows, there is a clear tendency for the number of good pastures to decrease in both treatments during the second stage, ending with about 67% of good pastures in each case. That is, the positive impact of collective property rights seems to diminish over time – a finding which questions at least the long-term efficiency of property rights in our study.

As in the open-access situation, we obtain a (weakly) significant positive effect for the PRS treatment compared to the PRC treatment ($Z = 1.75$; $p=.08$).[16] If we had not obtained such a big difference between the treatments in the open-access situation, we might easily have attributed the treatment difference in the second stage to the way we sorted the player types and put it down to the effect of the treatments. But unfortunately, the (coincidental) difference in the first 10 rounds limits the scope of judgements or evaluations regarding

[16] This is also in line with a multivariate analysis when we regress the grazing quality for the abundant resource A and the scarce resource area B on the treatment, while controlling for game history (see Table B.2 in the appendices): compared to the PRC treatment, we obtain a (weakly) significant increase in the number of areas in good grazing condition in areas A and B for the PRS treatment.

between-treatment differences when measured in terms of resource availability. However, when using double-difference estimations for group earnings (i.e. taking pre-treatment differences into account) we do not find a significant increase for the PRS treatment.

Keeping this in mind, we can nevertheless note as an intermediate result that both property rights sorting treatments seem to improve overall efficiency, as not only resource availability but also individual earnings increase significantly. The latter increase by about 10 units in *each* property rights treatment, from 50.67 to 60.63 tokens in PRS (t=3.91; p-value<0.01) and from about 45 to 55 tokens in PRC (t=3.65; p-value<0.01). As a consequence of declining resource availability in the long run (see Figure 1), individual earnings per round are lower in the last four rounds of the second stage (on average 5.1 units per round) than over the entire course of stage 2 (about 5.8 units per round), but still significantly higher than in the open-access situation.[17] Although the downward tendency of grazing availability questions the long-term efficiency of the property rights treatments, overall they improve efficiency.

3.3 Behavioral differences of player types

Having examined the overall efficiency of the assignment of property rights and the differences between the PRS and PRC treatments, we now analyze the differences in intensity choices and earnings between player types. In a first step, we investigate whether behavior revealed in stage 2 was either uncooperative (Hypothesis 2-a), cooperative (Hypothesis 2-b) or partly cooperative (Hypotheses 2-c and 2-d). We then examine the validity of Hypotheses 3a and 3b. Note that the only difference between Hypotheses 2c and 2d and Hypotheses 3a and 3b is that the former take into account the total sample, whereas the latter refer to player types' behavior in the PRS (Hypothesis 3a) and PRC (Hypothesis 3-b) treatments, respectively.

In stage 2, we observe a mean intensity of 1.33 units if we consider both treatments. The mean intensity of 1.33 is significantly different from 2 units (n=600; t=24.0; p=0.000). Consequently, the mean number of good grazing areas per group from rounds 13–20 (12 groups and 8 rounds) also differs significantly from zero (n=96; t=22.6; p=0.000) as do the average group earnings, which are 289 tokens in stage 2, and thus significantly above the 155.2 points (n=12; t=6.65; p=0.000) that would have been earned in the uncooperative equilibrium. We can thus clearly reject Hypothesis 2-a.

Next, we test whether our data fit the cooperative and similarly the partly cooperative equilibrium (hypotheses 2-b and 2-c). In contrast to these hypotheses, we find that rule breaking occurs in 13% of all cases and is thus significantly different from zero (n=600; t=9.7; p=0.000). Moreover, players assigned to area A play on average an intensity of 1.5, which is significantly lower than 2 units (n=213; t=-11.2; p=0.000), and B players apply average intensities of 1.18 units, which is significantly higher than 1 unit (n=305; t=4.6; p=0.000). Furthermore, the number of good grazing areas is significantly lower (an average of 1.5 per round) compared with the predicted solution of always having both areas in good condition (n=120; t=-7.27; p=0.000). As a result, the group earnings do not reach the predicted outcome of 370 (n=12; t=-4.01; p=0.002). Thus, the data do not support Hypotheses 2-b and 2-c.

[17] According to a two-sided t-test comparing mean individual earnings per round in rounds 7–10 with that obtained in rounds 17–20 (t=2.28, p=0.023).

Hypothesis 2-d considers a (hypothetical) scenario where the A-players of the total sample (i.e. the A-players of the PRS and PRC treatments) behave cooperatively, while their group members assigned to area B behave selfishly. However, as mentioned above, B-players do not always exert an intensity of 2 units (but on average 1.18), nor do players assigned to area A, not even in situations where their pasture is in good condition. Turning to rule following behavior, we also do not find any support for Hypothesis 2-d: in situations where grazing area A is high but area B is low, 28% of B-players move to area A rather than the 100% that was predicted (n=63; t=12.5; p=0.000). On the other hand, if area B is in good condition, players still go to area A in 12% of all cases, which is significantly different from zero (n=297; t=-40.5; p=0.000), and irrational since players earn a lower expected payoff from breaking the rule when their own area is in good condition (6.4 tokens compared to 8 tokens). Moreover, in the case of L_1L_2 (no matter whether their own or the other area is L_1), A-players should always choose area B with an intensity of 2. However, in only 25% of all cases do A-players choose area B with an intensity of 2 (n=12; t=-9.7; p=0.000). Also the probability of finding at least one good grazing area from round 12 onwards (9 rounds and 12 groups) is 0.92 and thus significantly different from 0.33 (n=108; z=13.1; p=0.000). Finally, group earnings are 289 tokens and thus much higher than the predicted 200.8 tokens by the partly cooperative partly uncooperative equilibrium

Summing up our hypotheses 2 (a, b, c, d) for the second stage, we find that all these have to be rejected.

While Hypothesis 2 takes the total sample from rounds 11–20 into account, Hypothesis 3 looks at either PRS (Hypothesis 3a) or PRC (Hypothesis 3b) treatment. We now restrict our sample to test Hypothesis 3-a for the PRS sample and Hypothesis 3-b for the PRC sample. These tests suggest that players fully revealed their behavior in stage 1 and are either selfish or cooperative. In stage 1, players afterwards classified as 'selfish' apply average intensities that are significantly higher than those chosen by 'cooperative' players in both treatments.

In the case of the partly cooperative equilibrium, where the selfish farmers are on area A and the cooperative farmers on area B (PRS treatment), we should be less likely to reject our hypothesis than we were with our Hypothesis 2-c where we analyzed the whole sample. In the PRS treatment we find that rule breaking still occurs in 11% of all cases, which is significantly different from zero (n=300; t=6.18; p=0.000); players assigned to area A play on average an intensity of 1.6 on area A, which is significantly lower than 2 (n=106; t=-7.2; p=0.000); while players assigned to area B play on average an intensity of 1.08 on area B, which is not significantly different from one (n=160; t=1.6; p=0.11). Furthermore, the number of good grazing areas is significantly lower (average of 1.7 per round) compared with the predicted solution of always having both areas in good condition (n=60; t=-4.8; p=0.000). As a result the group earnings of 303 tokens do not reach the predicted outcome of 370 (n=6; t=-4.22; p=0.009). Comparing these results with the results for Hypothesis 2-c based on the total sample, we observe a push towards our predictions in absolute figures and we find that the cooperative players assigned to area B are especially likely to play as predicted by our cooperative theory.

We now restrict our sample to test Hypothesis 3-b for the PRC sample. The tests are thus similar to Hypothesis 2-d but we should observe a tendency towards the predicted value if the sorting revealed (at least partly) player types. In the PRC treatment, players assigned to area B played a higher intensity in stage 1 than the other group members but still only chose an intensity of 1.3 on area B, which is significantly lower than 2 (n=145; t=11.4; p=0.000). In situations where grazing area A is high but area B is low, 33% of B-players move to area A.

This effect, however, is smaller than one and thus not as high as predicted (n=33; t=8.00; p=0.000). If area B is in good condition, players still go to area A in 16% of cases, which is significantly different from zero (n=147; t=6.3; p=0.000). Also, players assigned to area A do not play an intensity of 2 if their area is in good condition (n=94; t=7.3; p=0.000; instead they play an average of only 1.46. In the case of L_1L_2 (no matter whether their own or the other area is L_1), A-players should always choose area B with an intensity of 2. However, in only 25% of all cases do A-players choose area B with an intensity of 2 (n=12; t=-9.7; p=0.000). From round 12 onwards (9 rounds and 6 groups) the probability of finding at least one good grazing area is 0.85 and thus significantly different from 0.33 (n=54; z=8.15; p=0.000). Also group earnings are 275 tokens and thus much higher than the 200.8 tokens predicted by the partly cooperative partly uncooperative equilibrium (where the area A players are cooperative and the area B players selfish). Comparing the tests for PRC treatment with the rest of the sample (i.e. Hypothesis 3-b with 2-d), we find that in the PRC treatment it is especially the players assigned to area B (the selfish ones) who increase their intensity and play more as predicted by theory. However, the predictions do not capture the overall behavior of our participants very well. As stated earlier, we provide a broader analysis of the differences between the PRS and PRC sessions.

A comparison between player types (selfish vs cooperative) across treatments reveals remarkable differences in intensity choices, in situations of both high and low resource availability. A-players enjoy good grazing conditions in 83.33% of all cases, and in seven sessions (four in PRS and three in PRC) they even retain high resource availability over the entire course of the second stage. The two A-players in PRS, who behaved most selfishly in stage 1, enjoy high resource availability more frequently than their counterparts in PRC, who were the two most cooperative players in the first stage (88.33% compared to 78.33%), despite the fact that the former apply significantly higher intensities than the latter (1.69 compared to 1.58 units; t=1.944; p=0.053). Taking the whole sample, B-players enjoy good grazing conditions in roughly 76% of all cases (83% in the PRS and 68% in the PRC treatment). In such a situation, the three B-players in PRS, who behaved most cooperatively in stage 1, apply an average intensity of 1.16 units, while their counterparts in PRC, i.e. those who exhibited the most selfish behavior in stage 1, apply on average 1.51 units, which is significantly higher (t=4.84; p<0.01). Presumably as a direct consequence of lower mean intensities, in four out of six sessions the players allocated to area B in the PRS treatment were able to keep their pasture in good condition for all 10 rounds.[18] In terms of efficiency, it seems that assigning the more selfish players to the abundant area and the more cooperative players to the scarce resource, as was done in the PRS treatment, is ecologically beneficial, since high resource availability was maintained more frequently in the PRS treatment.

Once a grazing area has been overgrazed and thus become degraded, participants adjust their behavior and apply lower intensities, irrespective of the treatment or player types. However, as in situations of high resource availability, differences between player types across the treatments remain significant if we consider cases of low resource availability only. Resource degradation of area A happened more frequently in the PRC than in the PRS treatment due to a higher incidence of trespassing by B-players in PRC, which is discussed in more detail below. If A-players are confronted with a degraded field, those in the PRS treatment still choose higher intensities (on average 1.29 units) than their counterparts in the PRC who graze with 0.96 units. However, because the number of observations was small (n=38), the difference between the treatments is only weakly significant according to a one-sided t-test

[18] B-players in the PRC treatment maintained high resource availability over the entire course of the game in half of all sessions.

(t=1.34; p=0.09). Thus, those classified as selfish (the A-players in PRS) seem to be less willing to restore a grazing area that is in bad condition than players labeled as cooperative. We can draw similar conclusions for B-players: when area B is in bad condition, the selfish players assigned to area B (PRC treatment) apply a mean intensity of 0.8, while the cooperative B-players (PRS treatment) choose average individual applications of 0.5 units (t-value = 1.9; p<.1), which again indicates that cooperative players are more willing to cooperate for the sake of resource recovery and thus long-term profit maximization.

Finally, we investigate the effects of the assignment of property rights on the earnings of different player types. In doing so, we use random-effects GLS regressions, controlling for heterogeneous game history (Table 2) by regressing the following equation:

$$y_{i,g,t} = \alpha + \beta Treat_t + X_{i,t} + W_{g,t} + z_{i,t-1} + \mu_i + \varepsilon_{i,g,t}$$

where our dependent variable $y_{i,g,t}$ represents earnings for player *i*, in group *g*, and at time *t*. Furthermore, $X_{i,t} = \sum_{j=1}^{t-1} x_{i,j}$ are cumulated variables on the individual level (individual earning and difference in earning) from round 2 (alternatively 7) to *t*-1 and $W_{g,t} = \sum_{j=1}^{t-1} W_{g,j}$ is the cumulated variable on group level (standard deviation in earning) from round 2 (alternatively 7) to *t*-1. The group level variables are a function of the five individuals per group at time *t*. We also control for previous round effects at group level $z_{i,t-1}$ (resource condition) and include a random effect μ_i which we assume to be uncorrelated with the other covariates, as well as a random error term $\varepsilon_{i,g,t.}$ In addition, we provide standard errors that permit for correlation within the group (clustered standard errors). Finally, β measures the different treatment effects per player type where *A-PRS (selfish)* is a sub-treatment of PRS taking the value of one only for those two players who were initially assigned to area A (in the case of PRS the more selfish ones), and *B-PRS (cooperative)* is the sub-treatment for the remaining (more cooperative) three players in the PRS treatment who were assigned to area B.[19]

The regression analysis allows us to investigate the treatment effects on individual earnings compared to the open-access situation, separated for each player type (A or B). In models 1 and 2 of Table 2 we compare individual earnings in the last nine rounds of each stage to capture the overall treatment effect. We further evaluate the long-run efficiency of the property rights treatments by comparing earnings in the last four rounds of each stage (models 3 and 4). That way, we account for the downward tendency of grazing availability in both property rights treatments depicted in Figure 1. The first and third models only include the treatment and an indicator for the round of the game. We consider the *round number*, since cooperation may increase or decrease over time, and we control for the *last round*, where we expect higher earnings and intensities as the players know that the game has only 20 rounds. The second and fourth models further include variables taking values that are cumulated until the previous round: individuals' profit (*Individual earning)*, the relative profit

[19] Thus, in the PRC treatment we have the following two subgroups: *A-PRC (cooperative)* refers to the two cooperative players assigned to area A and *B-PRC (selfish)* refers to the remaining three selfish players assigned to area B.

(*Difference earning*)[20] and the group standard deviation of earnings (*Stddev earning*). To control for the resource condition in the previous round, we consider *good condition*, a dummy variable taking the value of 1 if at least one area was in high condition in the previous round (i.e. for the resource scenarios HH, HL_2 and HL_1), and *bad condition*, a dummy variable that takes the value of 1 if the resource condition was L_1L_2 or L_1L_1 in the previous round. The reference category for these two variables constitutes the resource condition L_2L_2. We use lags of these game-related variables, since a player only knows what happened in the previous round when making his decision in the current round. The previous round and previous round cumulated variables help to explain the within- and between-individual variance. However, since the coefficients are endogenous and thus biased, we use them mainly to increase the efficiency of our treatment estimates, so interpretation should be done carefully.

When comparing the last nine rounds of each stage (rounds 2–10 and 12–20), we obtain significantly higher individual earnings for all sub-treatments (Models 1 and 2 in Table 2). The cooperative players in the PRC treatment (*A-PRC (cooperative)*) especially benefited substantially from the assignment of collective property rights and increased their returns from 40 to 58 tokens. However, we do not observe a significant increase in earnings for any of the sub-treatments when restricting our analysis to individual earnings obtained in rounds 7–10 and 17–20 (models 3 and 4 in Table 2). This finding reflects the diminishing efficiency of property rights indicated by the downward tendency in Figure 1.

Table 2: A comparison of earnings between stage 1 and stage 2 for different player types

Y: **Individual earnings**	Rounds 2–10 vs 12–20		Rounds 7–10 vs 17–20	
	Model 1	Model 2	Model 3	Model 4
A-PRS (selfish)	3.257***	1.865**	0.659	0.115
	(0.870)	(0.775)	(2.156)	(2.051)
B-PRS (cooperative)	3.001***	2.056**	0.728	1.111
	(0.912)	(0.847)	(2.765)	(2.644)
A-PRC (cooperative)	3.489***	2.451***	1.638	1.352
	(1.021)	(0.689)	(2.113)	(2.134)
B-PRC (selfish)	2.370***	1.408**	0.144	0.066
	(0.917)	(0.664)	(1.989)	(2.095)
Cumulated until previous round				
Individual earning		0.027		0.032
		(0.022)		(0.025)
Difference earning		0.031*		0.035
		(0.019)		(0.022)
Std dev. earning		-0.014		-0.069
		(0.044)		(0.063)
Resource condition in previous round				
Good condition		4.498***		3.932***

[20] Relative profit = own profit – (others' profit / n-1)

		(0.520)		(0.692)
Bad condition		2.427***		2.968***
		(0.509)		(1.105)
Round number	-0.188**	-0.231	-0.018	-0.081
	(0.084)	(0.198)	(0.232)	(0.343)
Last round	0.764	0.441	0.697	0.735
	(0.729)	(0.751)	(0.731)	(0.626)
Constant	5.641***	1.404*	4.539**	1.258
	(0.585)	(0.783)	(2.089)	(2.064)
Observations	1,080	1,080	480	480
r2_w	0.063	0.107	0.037	0.046
r2_b	0.018	0.744	0.003	0.602
r2_o	0.055	0.189	0.016	0.180

Notes: The model is estimated using a random effects GLS regression. The dependent variable is individual earnings. Models 1 and 2 compare earnings in the last four rounds of each stage. In estimations 3 and 4 we compare earnings realized in rounds 2–10 with those realized in rounds 12–20. Cluster-robust standard errors are in parentheses: *** p<0.01, ** p<0.05, * p<0.1.

As regards the distributional effects of the two property rights treatments, we find smaller standard deviations of earnings in PRS than in PRC, for both A-players (PRS=12.2; PRC=19.9) and B-players (PRS=15.3; PRC=21.4). However, the overall variation for the group of five players is larger in PRS since the difference in mean earning between the two players on area A (PRS=66; PRC=58) is much higher than on area B (PRS=56; PRC=52). Thus, the assignment of property rights to those with the highest initial intensity in stage 1 increases the inequality between the rich and the poor.

3.4 Motives for rule breaking

While the occurrence of resource degradation in location B might be attributed to a lack of cooperation among B-players, the single reason for the degradation of grazing area A is trespassing by B-players.[21] As outlined above, A-players in the PRC treatment face resource degradation more frequently than their counterparts in PRS, indicating that they were more frequently victims of harmful trespassing. Indeed, univariate and multivariate analyses[22] reveal that B-players in PRC, i.e. the most selfish players in the first 10 rounds, enter area A significantly more often than the cooperative B-players in treatment PRS (Z=2.019, p=0.028): The former trespass 33 times (i.e. in 18.3% of all possible cases) and thus almost twice as often as their counterparts in PRC, who break the rule 17 times (the frequencies of rule breaking, separated by treatment, are shown in Table 3). The incidence of A-players entering area B, on the other hand, is not statistically different for the two treatments (Z=0.2, p=0.84), though (selfish) A-players in PRS trespass slightly more often than their counterparts in PRC (14 compared to 12 times). Overall, rule breaking happens more

[21] Note that a cooperation failure between A-players cannot be the cause, since even if both players applied an intensity of 2 units, the threshold of 5 units would never have been exceeded.

[22] We ran random effects probit estimations where we regressed subjects' rule-breaking behavior on several covariates, including categorical variables for the treatment and the grazing area that was trespassed on, a variable that captures the possible profit subjects could obtain from trespassing, round variables, game-related variables controlling for subjects cumulated earnings, their relative earnings compared to those of other group members, and groups' standard deviation of earnings. The random effects are on an individual level, to incorporate correlations in the behavior over time. The results are presented in Table B.3 in the appendices.

frequently in PRC than in PRS. However, the difference is only weakly significant according to a Mann-Whitney test (Z=1.66, p=0.096), and the significance disappears in a multivariate regression analysis, when we regress subjects' rule-breaking behavior on several covariates, including the possible profit they could obtain from trespassing (see Table B.3 in the appendices). The multivariate regression results further suggest that trespassing is motivated by payoff considerations, as it happens significantly more frequently if the possible profit is positive (Table B.3 in the appendices). It is further interesting that the frequency of being monitored and sanctioned does not affect rule compliance significantly. This is somewhat discouraging, as it implies that monitoring and subsequent sanctions do not change behavior in favor of less trespassing.

Surprisingly, subjects also trespass in situations where their grazing area is in good condition (in about 9% of all cases) and there is thus no economic incentive for trespassing (Table 3), though they break the rule relatively more frequently in situations where their predefined area is degraded (in 26% of all cases).[23] Trespassing happens in situations of high resource availability and can also be observed for A-players. Cases where one or both grazing areas were overgrazed and thus became degraded at least once during the 10 rounds of stage 2 happened in 8 out of 12 sessions. However, in only two of these sessions was the second grazing area thereupon also affected by overgrazing, but no group found itself stuck in a situation of low resource availability in either location until the end of the session.

Table 3: Trespassing of A-players and B-players in the property rights treatments

Trespassing	PRS			PRC		
	A-Players (selfish)	B-Players (cooperative)	Sum	A-Players (cooperative)	B-Players (selfish)	Sum
Total trespassing	**14**	**17**	**31**	**12**	**33**	**45**
When own pasture HIGH	**10**	**10**	**20**	**5**	**18**	**23**
On HIGH pasture	*6*	*10*	*16*	*5*	*17*	*22*
On LOW pasture	*4*	*0*	*4*	*0*	*1*	*1*
When own pasture LOW	**4**	**7**	**11**	**7**	**15**	**22**
On HIGH pasture	*4*	*7*	*11*	*5*	*10*	*15*
On LOW pasture	*0*	*0*	*0*	*2*	*5*	*7*

More astonishingly, A-players in PRS break the rule even when area B is in bad condition and the condition of their own grazing area is good. This happened in 4 out of 14 cases. In one PRS session, grazing area B was degraded because of trespassing by A-players and then remained in low quality for five successive rounds just because an A-player trespassed twice right at the point where area B would have recovered in the following round. This behavior is not driven by economic incentives, because the condition of A was high then, and the possible profits from rule deviation were thus far below those that could be obtained by rule compliance. This kind of spiteful behavior has been observed in related studies and has been

[23] As Table 4 shows, rule breaking happened 43 times if the trespassing subject faced high resource availability and 33 times if his or her predefined area was in bad condition. In about 79% of all cases the grazing areas were in good condition.

explained by motives of revenge or payoff dominance, i.e. the desire to increase one's own relative payoff (Levine, 1998; Casari & Plott, 2003; Falk et al., 2005; Fehr et al., 2008; Abbink & Sadrieh, 2009). However, revenge as a motive, as has been identified in recent studies on punishment behavior in public good experiments (Gächter & Herrmann, 2006; Herrmann et al., 2008; Nikiforakis. 2008), can be excluded as an explanation since B-players did not trespass in the previous rounds of that session and thus there was no motive for exacting revenge. Neither can the observed behavior be explained by an individual's desire to increase his or her relative payoff, as this could have been achieved more easily if the subject grazed on the predefined area A. However, it might be that this player merely enjoyed decreasing the earnings of others and was willing to pay for this by accepting an expected return of only 1.6 instead of the 8 tokens that he or she would have earned for sure by not trespassing. Since this player recorded the right tokens in her own player record sheet, confusion as a further potential explanation can be excluded.

Interestingly, resource degradation in location B was mostly caused by the trespassing of A-players as well, rather than by B-players' failure to cooperate. In the six sessions of the PRS treatment, location B moved from high to low resource availability only three times, always because of trespassing. In the PRC treatment, A-players' rule deviation still caused 66% of the cases where grazing area B moved from good to bad condition, thus some of the 'cooperative' A-players also behaved antisocially in a way.

In summary, we obtained the following results regarding rule following behavior: first, trespassing happened more frequently on area A than on area B. Second, trespassing also happened in situations where the expected profit was lower than that obtainable from rule compliance. Third, resource degradation was mostly caused by trespassing rather than by resource overexploitation. Fourth, monitoring and sanctioning did not affect rule compliance significantly. Last, players who behaved most selfishly in the first stage were significantly more likely to trespass than those who behaved most cooperatively in stage 1.

4. Conclusion

To the best of our knowledge, this study is the first attempt to test the effect of assigning unequal collective property rights to resource management in a commons dilemma. The innovation in our experiment is to have two areas with well-defined collective property rights that are intended to solve the inherent coordination problem. In stage 2 of our experiments we test whether social preferences interfere with the way collective property rights are assigned. We model two extreme cases where property rights to an abundant resource are assigned either to selfish players (*property rights for selfish* – PRS) or to cooperative players (*property rights for selfish* – PRC). Our PRS treatment is based on current practices in Namibia and South Africa of granting property rights according to prior use, which is according to Roemer (1989) also Pareto-optimal. In the absence of behavioral differences between players, both treatments should work identically, since in both cases two players are allocated to area A, where resources are abundant, and three players to area B, where resources are scarce and hence cooperation is required.

We find that assigning property rights in either way increases the number of good grazing areas and earnings. We further observe that players in all sub-treatments increase their grazing intensities. Because overall grazing availability is nevertheless better in stage 2 than in stage 1, we can conclude that the allotment of property rights enhances ecological and economic efficiency, at least in the short term. However, the beneficial effects diminish over time, as rule breaking increases over the course of the game, so that it remains unclear whether the treatments are beneficial in the long term. Comparing the two treatments, we find some weak evidence that PRS works better than PRC in terms of efficiency. Grazing quality, measured as the percentage of pastures in good condition, is higher on area A as well as on area B in the PRS treatment, leading to higher earnings for A- and B-players. The PRC treatment, on the other hand, reduces inequality among the players. Our results also show that social preferences are stable over the course of the game. Subjects classified as 'cooperative' indeed behave more cooperatively if assigned to area B (PRS treatment), i.e. they apply lower grazing intensities to avoid resource degradation and thus gain higher revenues in the long term, than their counterparts on area B (PRC treatment), to which subjects who behaved more selfishly in the previous rounds were assigned. The higher propensity to cooperate among B-players in PRS is reflected in the fact that they would not have overexploited their pasture if A-players had not trespassed and thus destroyed their resource. Moreover, B-players in PRS break the rule less frequently, i.e. trespass less frequently on area A than B-players in PRC. We observe similar behavioral differences between the A-players: A-players in the PRC treatment (the cooperative types) apply lower grazing intensities and trespass less frequently on area B than the A-players in the PRS treatment, who were most selfish in the first stage. Thus, it seems that social preferences matter a great deal, since we generally observe a strong consistency in behavior throughout the game.

However, what matters here is not just efficiency but also the role of the state, the endowment of social capital and the redistributive impact of privatization. Though the policy implications of our results are limited because of the small sample size, our study nevertheless suggests that the Namibian and South African government policy of granting farmers access to private farms may be an appropriate strategy to reduce resource pressure on the commons and to make efficient use of scarce land. However, our results hold only for the assumption of perfect enforcement and only if there are abundant resources in the location allocated to the resettled farmers. In addition, resettled farmers must be prohibited from using the village commons once they have been resettled. The flip side of the coin is that these property arrangements create a skewed distribution which provokes envy and spite. Thus, if property rights are imperfectly enforced, people may start breaking property rules and making spiteful attacks, as we observed in our experiments and also in everyday life in our study area. Of course, our results do not imply that the resettled farmers are more spiteful, since many other factors (most importantly budget constraints and ecological factors) lead to larger herd sizes or higher intensity of grazing, which we used in our experiment as a label for more selfish farmers. However, there are further similarities, since cooperative players in our sample are more likely to have lower household income and larger families. Thus, we argue that our study provides insights into the role of pro-social and anti-social preferences in managing a scarce resource.

A final remark should be made about an upcoming debate on the role of spite in the development process of countries. Gächter & Herrmann (2006) and Herrmann et al. (2008) argue that spiteful punishment may undermine cooperation, and thus self-governance may work only in certain regions of the world. Fehr et al. (2008) show in a series of dictator games in India that high-caste subjects especially behave spitefully and forego earnings in order simply to decrease another person's payoff. They argue that the lower ability to cooperate and the use of spiteful action may be due to the high-caste subjects' concern for status and superiority. This finding is similar to our result, as we also observe a fraction of the already privileged farmers destroying the resources of the less privileged, which in turn may have detrimental effects on cooperation in the long term.

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Appendix A: The game equilibrium

In this section we develop the game equilibrium for cooperative and uncooperative play in each stage of the game.[24] We first examine the first stage of the game, i.e. rounds 1 to 10, where no property rights are in place, and thereafter the second stage, where property rights have been introduced. In each stage, various different equilibria are possible. If all participants are selfish and aim for profit maximization, they will always choose an intensity of 2 on the area with highest grazing quality. As this leads to rapid degradation of the grazing areas, the total group payouts are suboptimal. Alternatively, if all subjects play more cooperatively, they can obtain the maximum payout. If communication were possible, all participants could coordinate to achieve the highest group payout. Since communication was not possible in our experiments, we establish the equilibrium strategy where all players plan to cooperate but cannot coordinate.

In the second stage of the game, more equilibria are conceivable since the participants differ according to their assigned property rights: two players are assigned to area A and the other three to area B. While area A and area B are symmetric, the key difference is that area A is shared by two players and area B by three. The uncooperative equilibrium is straightforward to establish. The cooperative solution could be more complex. We examine three different cases: both area A and area B players cooperate, area A players cooperate and area B players do not cooperate (i.e. they are short-run payoff maximizers), and vice versa.

The game equilibrium without property rights (rounds 1 to 10)

The non-cooperative equilibrium

In this subsection we derive the uncooperative equilibrium, i.e. the expected behavior when all players behave selfishly in every round. The highest payout is obtained by always choosing an intensity of 2 and the area with the best grazing quality. Nevertheless, there are two uncooperative equilibria, depending on whether people's selfishness is myopic or deliberate. This difference matters when the grazing situation is L_1L_2 (or L_2L_1 since the setting is symmetric). The myopic players realize that the payout is identical for both areas and randomly choose either of the two areas. The deliberately selfish players on the other hand realize that if everyone chooses the L_2 area, the other area could recover and become a high quality area H with high earnings potential for the next round for everyone. On the other

[24] We thank a referee for suggesting this analysis.

hand, if everyone chooses the L_1 area, this area will be degraded and the other area can be upgraded only to L_1. They thus realize that it is better for everyone to choose the L_2 area.

Hence, there are two uncooperative strategies: *myopic selfishness* and *deliberate selfishness*. In both cases, the game starts with HH, and in the next round one area becomes degraded and the situation is HL_2. Then all players choose the good area, thereby leading to the situation L_2L_1. Now, if all players are myopic, they will choose the area randomly and an intensity of 2. Unless by chance it happens that all players randomly choose the L_2 area (which happens only with probability 3.125%), the L_1 area will be degraded and the grazing situation will be L_2L_2. Now the recovery of either area becomes very unlikely since it would have to rest for two consecutive rounds. The probability of this is only $½^4 \cdot ½^5$ = 0.195 %. Hence, it is most likely that the grazing situation will remain L_2L_2 forever. Then the total group earnings in every round will be 2·5=10. (The sum of the earnings over the first 10 rounds will be 160 because higher earnings are achieved in the initial good grazing situation.)

In contrast to the myopic selfishness, the deliberate selfishness equilibrium is different from round 3 onwards. At the beginning of round 3 the situation is L_2L_1. Now every player chooses intensity 2 on the L_2 area such that area L_1 can recover, leading to the situation L_2H at the beginning of round 4. Hence, at the beginning of round 4 (and 6, 8, 10 etc.), participants will face the same situation as in round 2, with one grazing area in good and the other in bad condition (HL2). This leads to an automatic rotation system. Thus, the group earnings are 40 in rounds 2, 4, 6, 8 and 10, and 10 in rounds 3, 5, 7 and 9. In the long run the average group earnings are thus 25 per round. (The total payout from round 1 to 10 is 280 because of the higher payout in period 1.)

The main testable distinction between these two equilibria is in the behavior when the grazing situation is L_1L_2. Under deliberate selfishness the area L_2 should be chosen with probability one. Under myopic selfishness the area L_2 should be chosen with probability 0.5. In addition, under myopic selfishness the probability that at least one of the two grazing areas is of high quality is very close to zero from round 3 onwards. Under deliberate selfishness, in every second round at least one area is of high quality. This is formalized in Hypothesis 1 in the paper.

The cooperative equilibrium, with communication

The highest group payout can be obtained if two players choose an intensity of 2 on one area, two players choose an intensity of two on the other area and the last player chooses intensity 1. In this case neither of the areas is degraded and the situation always remains HH. The group payout in every round is then 4•8+7 = 39 per round.

The cooperative equilibrium, without communication

Since the participants could not communicate during the experiments, the previous optimum solution is not possible. We now derive the cooperative equilibrium, i.e. the strategy that maximizes the social payout, when coordination is not possible. We also exclude the possibility of signaling, i.e. that participants intend to communicate via their intensity and location choices in order to signal their intended behavior for the future. Such tacit communication would be difficult to establish, and particularly so during the first 10 rounds of the game that we observe.

In each round, each player has five options: intensity 0, intensity 1 on area A, intensity 1 on area B, intensity 2 on area A, intensity 2 on area B. All players are identical and have the same choice options. The state space consists of the qualities of the two grazing areas as well as the group intensity choices of all previous periods. Since we focus on the long-run game equilibrium, and to simplify the derivation, we reduce the state space to the situation of the grazing areas at the beginning of the current round. We further assume that the players consider area A and B as symmetric, i.e. they are rational in the sense that they do not prefer the letter A to the letter B or vice versa. Then the state space contains only 6 elements: HH, L_1L_1, L_2L_2, HL_1, HL_2, L_1L_2.

The optimal strategy vector defines, for each of the six elements of the state space, which of the five grazing choice options should be chosen in order to obtain the maximum group payout. In other words, for each of the six situations, the optimal choice can be different, and this is something we can test in our empirical application. We make two further assumptions. First, players do not deliberately play mixed strategies (with one exception, as discussed below). This appears natural for people living in close-knit communities who often depend on mutual trust and insurance.[25] For such people, keeping a reliable reputation is often important, i.e. either a person always steals your cattle or never does so, but stealing your cattle only sometimes may not be a natural choice (since the good reputation would be lost anyway). Therefore, we do not examine mixed strategies. Second, people cannot communicate, as was the case in our experiments, or signal their future intentions via current choices, which would be difficult to establish within the first 10 rounds of the game only.

Hence, the optimal strategy vector defines one optimal grazing choice for each of the six situations. However, in the symmetric situations HH, L_1L_1, L_2L_2, it does not make a difference whether one chooses area A or B. If we assume that players do not prefer the letter A or B per se and because they cannot communicate, they basically choose randomly. This, quite natural, simplification reduces the complexity of the strategy vector, but makes the calculation of the equilibrium more complex. For example, suppose the grazing situation is L_1L_1 and all participants choose intensity 1. If one area is chosen by two and the other by three participants, both areas will become degraded and this will lead to the situation L_2L_2. However, it can also happen by chance that four or five participants graze on the same area. In this case, the other area will recover, thereby leading to the situation HL_2. To incorporate this randomness of the area choices when grazing quality is symmetric, we use stochastic simulations, as we discuss below.

Hence, with this simplification of the symmetric grazing situations, we obtain the following strategy space: in each of the three symmetric grazing situations HH, L_1L_1, L_2L_2, each player has three choices (intensity 0, 1 or 2), with the area being chosen randomly. In each of the three asymmetric grazing situations HL_1, HL_2, L_1L_2, each player has five choices: intensity 0, intensity 1 on good area, intensity 2 on good area, intensity 1 on bad area, intensity 2 on bad area. Considering each player as identical and not permitting mixed strategies (except for the random area choice when the grazing qualities are identical), there are thus in total 3•3•3•5•5•5 = 3,375 different possible strategies. This large number of possible strategies, where many entail random area choices, makes an analytic solution for the optimal strategy cumbersome. We therefore make use of stochastic simulations to determine the optimal solutions. For each possible strategy, we let the game evolve for 100 rounds and repeat the entire process (i.e. always starting again with the initial grazing situation HH) 1,000 times to average out the randomness from the area choices in the symmetric grazing situations. (In

[25] We thank the referee for pointing this out.

fact it turned out that the optimal strategy did not change when we changed the length of the game to 10 rounds or 1,000 rounds and was also independent of the number of repetitions.) The optimal strategy vector is

When the grazing situation is HH: Choose intensity 2 on the good area

When the grazing situation is HL_1: Choose intensity 2 on the good area

When the grazing situation is HL_2: Choose intensity 1 on the good area

When the grazing situation is L_1L_1, L_1L_2 or L_2L_2: Choose anything.

If all players follow this strategy, the average group payout is 37.5 per round. In the first round, everyone chooses intensity 2, which leads to the degradation of exactly one grazing area. Thereafter, everyone chooses intensity 1 on the good area. The good area will thus not be degraded, and the bad area can rest for one round. Thereafter, everyone chooses intensity 2 on the good area, which will be degraded. The other area, however, has rested for two rounds in the meantime and thus recovered. The game then cycles between the situations HL_1 and HL_2. The situations L_1L_1, L_1L_2 and L_2L_2 thus never occur such that the optimal behavior in those situations is irrelevant and thereby undefined. The total group earnings for rounds 1 to 10 are 375.

From the above discussion we derive Hypothesis 1 in the paper.

The game equilibrium with property rights (rounds 11 to 20)

Now we establish the cooperative game equilibrium for the situation with property rights, i.e. for rounds 11 to 20. The situation is now more complex since the players are no longer symmetric: some are assigned to share a grazing area with two other players, whereas some are supposed to share with only one other player. Hence, there are two types of players with different 'property rights'. In addition, the two grazing areas are no longer symmetric, as each player needs to distinguish between 'own area' and 'other area'.

The non-cooperative equilibrium

We first derive the non-cooperative equilibrium, where everyone is maximizing individual payout via backward induction. Again everyone chooses intensity 2 in every situation, but in contrast to stage 1 there is now only one uncooperative equilibrium because of the penalty for trespassing. When the grazing situation is L_1L_2, the payout is no longer identical on both areas because the penalty risk when trespassing leads to a lower payout on the 'other area'. In the first round everyone chooses intensity 2 on their own area, leading to the situation HL_2, because only two players graze on area A. In the second round, everyone chooses intensity 2 on area A, since the expected payout when trespassing to A is 8•0.8 and thus higher than on the low-quality area. This leads to the situation L_2L_1. Now everyone grazes with intensity 2 on his own area, since trespassing would lead to a lower payout. Both areas will now remain as L_2L_2 forever. Hence, from round 13 onwards the total group earnings are 10 every round. (The total expected group earnings for rounds 11 to 20 are 155.2).

The cooperative equilibrium, with communication

The social optimum, i.e. the highest expected total group payout, is not changed by the introduction of property rights. The two players assigned to area A choose intensity 2 on area

A, and the other three players choose area B, with two of them choosing intensity 2 and one intensity 1. Since no player deviates from the assigned area, no penalties apply and the group payout in every round is 4•8+7 = 39.

The cooperative equilibrium, without communication

The previous equilibrium is not possible since players cannot communicate and therefore cannot coordinate who should be the person choosing intensity 1, while all others choose intensity 2. Now we derive the cooperative solution without communication. We have to take into account that the players are no longer symmetric: some are assigned to share a grazing area with two other players, whereas some are supposed to share with only one other player. Hence, there are two types of players with different 'property rights'. In addition, the two areas are asymmetric, since for each player we have to distinguish between 'own area' and 'other area'. Hence, there are nine different grazing situations HH, HL_1, HL_2, L_1H, L_1L_1, L_1L_2, L_2H, L_2L_1 and L_2L_2. In each round, each player has five different choice options: intensity 0, intensity 1 on area A, intensity 1 on area B, intensity 2 on area A, intensity 2 on area B. We further have to distinguish between the area A players (i.e. those two who are assigned to area A) and the area B players (i.e. those three who are assigned to area B). Although their choice options are identical, their payouts differ since those who graze on the 'other area' face a penalty if detected. (We implement this penalty by multiplying the payout by 0.8, which corresponds to the expected value of not being detected. This ensures that the game contains no random elements.) Hence, the strategy space of each player contains 5^9 elements and since there are two types of players the total strategy space contains $5^9 \cdot 5^9 = 3.81 \cdot 10^{12}$ elements. For each of these strategies we simulate which one leads to the largest group pay-out in the long run. It turns out that the equilibrium strategy is very simple:

When the grazing situation is HH: Area A players choose intensity 2 on area A and area B players choose intensity 1 on area B.

This means that neither of the grazing areas ever gets degraded and the situation always remains HH. This also means that the optimal choice in the other eight grazing situations is undetermined as these situations never occur. The average group payout is 37 per round.

The partial cooperative equilibrium, without communication

The asymmetry of the area A players and the area B players permits us to examine two more equilibria: one where the area A players are selfish and the area B players are cooperative (i.e. want to maximize total group payout), and one where the area A players are cooperative and the area B players are selfish. This could be particularly interesting because of the way these two groups were formed in the experiments: in half of the sessions, the two most aggressive players in a group (i.e. those with the highest earnings) were placed on area A. In the other sessions, the two players with the lowest earnings in a group (presumably the least aggressive) were placed on area A. If the previous behavior of these participants reveals anything of their type, we would expect the least aggressive players also to behave more like the cooperative players in the simulations below.

Area A players selfish, area B players cooperative

Consider first the situation, where the two players on area A always play selfishly: they always choose intensity 2. They always choose area A in order to avoid the penalty, unless area B is of better quality; i.e. only in the situations L_1H or L_2H do they choose intensity 2 on area B because the payout is higher even after deducting the penalty.

Since the strategy of the area A players is fixed, the strategy space of the area B players has 5^9 = 1,953,125 elements. If the area B players intend to maximize total earnings (which in fact also maximizes their own subgroup earnings), it turns out that their optimal choice is

When the grazing situation is HH: Area B players choose intensity 1 on area B.

This means that neither of the areas ever gets degraded (such that the strategies in the other grazing situations are irrelevant) and the solution is actually identical to the full cooperation equilibrium found before. The average group payout is thus again 37 per round.

Area A players cooperative, area B players selfish

Finally, we consider the reverse situation, where the three players on area B always play selfishly: they always choose intensity 2 on area B in order to avoid the penalty. Only in the situations HL_1 or HL_2 do they choose intensity 2 on area A. Now the strategy of the area B players is fixed, such that the strategy space of the area A players has 5^9 = 1953125 elements. If the area A players are cooperative, their optimal choice is the following:

When the grazing situation is HH: Area A players choose intensity 2 on area A.

When the grazing situation is HL_2: Area A players choose intensity 2 on area A.

When the grazing situation is L_1L_2: Area A players choose intensity 2 on area B.

When the grazing situation is L_2L_1: Area A players choose intensity 2 on area B.

This means that in the first round area B gets degraded, leading to the situation HL_2. In the second round, area A gets degraded, leading to the situation L_2L_1. Then all players choose area B, leading to the situation L_1L_2. Again all players choose area B, leading to HL_2, where the cycle begins again. The situations HL_1, L_1H, L_1L_1, L_2H and L_2L_2 thus never occur. The average group payout is then only 18.09 per round (when the game is played for 100 rounds). (The expected total group earnings for rounds 11 to 20 are 200.8.)

Hence, the equilibrium where the area B players are selfish leads to much lower earnings than the previous equilibrium where only the area A players were selfish.