How members of a common deal with inspection and overcrop

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Abstract. An usual common consists of a common property resource and members interacting and managing the resource. The dynamics of the resource depends on its natural growth and the concrete acts of appropriation by the members. It is well known that in the standard case the resource is endagered to be overexploited if the members of the common behave but selfinterested. Nevertheless both experiments and field research prove that members may succeed in stabilising the common by cooperating sufficiently. Different institutional means are used for the stabilisation task. In our experiments and analyses we focus at use limitations combined with inspection. We observed a very poor performance of the institution and stable oscillation patterns. An attempt is made to explain what cognitions and social-cognitions may have shaped the observed behavioural patterns.

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1. Introduction

Resources like fish or water often exhibit the property of a common. What one user takes affects the chances for other users. Game-theoretical analysis of these commons prescribe an overuse of the resource for a large and relevant class of situations. From the field it is known that commoners often add institutions more or less adequate to handle the problem. The pure addition of meetings to install communication processes does not affect the incentive structure. Nevertheless in corresponding experiments it was observed that subjects reach results superior and more cooperative with communication than without this possibility.

In **experimental games** subjects are instructed how their own actions and the actions of their partners will affect their own payoff and possibly the payoffs of their partners. The formal game behind the experimental situation represents the structure of interdependence and the incentive structure. In order to make the formally given incentive structure of a player a valid one in the experimental situation, we usually pay the subject according to the final outcome of the game with monetary payoffs that are worth struggling for.

Most laboratory research on commons is done with a **social dilemma paradigm** (cf. Dawes 1980, Wilke/Messick/Rutte 1986, Liebrand/Messick/Wilke 1992, Schulz/Albers/ Müller 1994) refering to static or repeating n-person prisoners' dilemma (n-PD) or generalised n-PD games, situations that are nearer to a public good or public bad conflict than to the usual problems for managing a common. In case of (generalised) n-PD games a formal analysis yields inefficient Nash-equlilibria with dominant strategies. But the **main difference between the social dilemma (SD) and the commons dilemma (CD)** is not the property to admit a dominant strategy or not (e.g. in a generalised SD a concave production function induces a non-constant best reply), but that the individual action parameter x is used for the control of two processes in case of a SD (namely costs and production), but the control of three processes in case of a CD (namely costs, production and appropriation). The first task turns out to be not nearly as **complex** as the latter one.

Laboratory research refering to the **CD paradigm** is mainly promoted by the Bloomington Group (Gardner, Ostrom, Walker and others). Earlier setup had been introduced by Platt, Edney and Harper, Rapoport and others. Two specialised setups - representing extreme cases of resource dynamics - are prominent in contemporary research: The first is the OGW-paradigm (Ostrom/Gardner/Walker 1994) with a renewable resource, that produces a proportionally shared quadratic „harvest". The second is the GMW Paradigm (Gardner/ Moore/Walker 1994) dealing with a non-renewable resource.

Despite the theoretically established inefficiencies field research and experiments on non-exclusive use of resources have shown that people behave much more efficient than theoretically expected. Let us call the efficiency gain above equilibrium the **cooperation shift**. Since about 25 years experimentalists from different disciplines try to explain what factors govern the amount and the dynamic stability or instability of the cooperation shift, using the prisoner's dilemma-, the social dilemma-, and the commons dilemma-paradigm.

For the perfectly renewable resource we get similar cooperation shifts as in social dilemmas. In the more difficult or conflictual task of the non-renewable resource subjects produced outcomes even poorer than (subgame perfect) equilibrium (Gardner/Moore/Walker 1994). [In our view the different tasks described above are ordered by some degree of complexity. This is why some findings originally won in a less complex task and also the respective research strategies may be important for the management of difficult common pool resources too].

Besides the parameters of the the game,. situational parameters beyond the game, and psychological, demographic, and cultural factors may be crucial for cooperation shifts. Let us end this section with a remark on two prominent situational parameters: **communication and asymmetry**. Beside focussing on group interest communication can serve as coordination device: especially in case of multiple equilibria it may be profitable to agree upon the choice of a specific one. In asymmetric settings the choice of a specific equilibrium cannot be facilitated by an undisputed equality norm.

By communication users can agree to use limitations, even if there is neither a device to identify potential users nor a technical solution to limit the individual take. But it is near at hand to add institutions of monitoring and sanctioning whenever commoners feel that communication alone may be not sufficient for protecting the resource.

This paper reports on an experimental investigation on how (costly and partial) monitoring and sanctioning of offenders affects the incentive structure and the behaviour of the commoners. The central finding focused here is that despite of the fact that controls and sanctions shift the Nash-equilibrium to a more favourable outcome the members of the experimental common do worse than the new equilibrium. In that sense the cooperation shift observed is negative. Therefore the experimental results suggest that the potential increase of efficency by inspection has to be judged very carefully. Political recommendations made on the base of the general assumption (for an example see Harvey/Bell/Birjulin 1993) that by setting the adequate inspection probabilities and sanctions we can gain or regain prosperity of the common are highly questionable.

2. Games and experimental setups

2.1 Classes of games, classes of setups

The members of a common commonly own a resource or facility that is jointly used and managed. These individuals are not excludable from use. Moreover they are rivals in use. The use of one member results in so-called negative **external effects** for his or her partners. If you think of a jointly used pasture or a jointly used aquifer a unit grassed or extracted cannot be harvested twice. If the development of the common becomes critical, then usually the members invent institutional means to enhance performance.

The first group of **institutions** that maybe implemented are meetings for providing communication possibilities. In a second step members may agree on individual use limits, and since usually the individual use cannot be observed, in a third step they may install a control mechanism and sanctions for those that do not respect the limit of use.

Formally the one-period incentive structure of the common can be represented by a **normal-form game**. In the base case, where no institutional means of enhancement are implemented, acorresponding game canbe defined.

Taking for granted that we can measure individual actions and outcomes on a cardinal scale, let x be the individual action of one of the n members and y the total of the actions of all her or his (n-1) partners. Then

(1) $u(x,y) = -cx + qf(x+y)\,,\ c>0$

together with some function $q=q(x,y)$ may represent the gain the member gets from the joint action profile (x,y). The term cx represents (linear) private cost, and f(x+y) joint product. The production function is assumed to be concave and normal (i.e. f(0)=0, „no product without effort").

The function q represents the „quotas" of how to distribute the joint product among the members. A public good can be represented by setting $q = 1/n$. Equally distributing the joint product generalises the n-PD to a social dilemma game. Binary action spaces, linear costs and linear production induce the n-PD game with its dominant strategies. In case of continuous action spaces and concave production usually there is no dominant strategy (best replies are not constant).

In case of a common the quota q is given by the proportional rule:

(2) $q = x/(x+y)$.

The set of actors $N=\{1,2,..,n\}$, the action spaces X_i, $i \in N$, and the payoff functions of the type above (formula (1) and (2)) define a normal-form game that represents the incentive and interdependence structure the members are facing.

For simplicity let the game be symmetric, i.e. $X_i = [0,w]$.

In case of **costless communication** facilities the communication strategies have no influence on the payoff structure. Thus the corresponding game can be identified with the base game.

The starting point for the dispute on the so-called **commons dilemma** is the following **theorem**:

The unique (and symmetric) **Nash-equilibrium** (in case best replies are not bound by the restrictions) has to fulfill the fundamental equation

(3) $(n-1)(f'-f/s) = n(f'-c)$

The Nash-equilibrium is inefficient compared to the joint (equally distributed) **welfare optimum**.

The class of the above games is the same, that can be derived by private linear production d and concave joint costs h. In this case the payoff functions are of the following form:

(4) $v(x,y) = d(x)-qh(s)$, $s=x+y$

In order to show the correspondence let $d_0 = f'(0)$ und $h(s)=cs+d_0s-f(s)$. Then:

(5) $v(x,y) = d(x)-qh(s) = xf'(0)-qcs-qf'(0)s+qf(s) = xf'(0)-cx-xf'(0)+qf(s) = u(x,y)$

Since average product f/s is larger than marginal product f' by concavity and normality of f, we get c>f'. The latter inequality shows inefficiency. Consequently the incentive structure may lead members to overuse. Formally the unique Nash-equilibrium prescribes a total use larger than optimal total use (usually called welfare optimum). The specification of the joint production function as concave is typical for a broad class of commons.

In the experimental setups I like to discuss throughout this article a normal form game of the above type is **finitely repeated**. The equilibrium is given by repetition of the one-stage Nash-equilibrium strategies. In case the common refers to a common pool resource this setup corresponds to a totally renewable resource.

As reference point for the experimental investigation of a control and sanctioning regime the **Ostrom-Gardner-Walker paradigm** is used as reference point. This paradigm specifies the parameters of the game as follows:

rounds:	20
members:	8
endowment	w=10 or 25
costs:	c=5
production:	f(s)=(a-bs)s, a=23, b=0.25

The corresponding (one-stage) solutions are:

solutions	strategy x	total return f(s)-cs
welfare optimum	4.5	324
equilibrium	8	128

The **Saarbrücken scenario** adds an individual use limit of 5, control, and sanctions. This institution essentially changes the incentive structure. An assumption usually made on the basis of this change is that by setting the adequate inspection probabilities and sanctions we can gain or regain prosperity of the common.

2.2 Adding external control

By communication users can establish and agree upon use limitations, even if there is neither a device to identify potential users nor a technical solution to limit the individual take. It is near at hand to add institutions of monitoring and sanctioning whenever commoners feel that communication alone may be not sufficient for protecting the resource.

We consider the following **scenario**: commoners have agreed on a limit λ for individual use. If the group does not succeed in establishing a stable and satisficing development of the resource they may find it useful to introduce monitoring the compliance with this norm.

Under the new regime for the common pool resource **setting up monitoring** is costly. This is why control is carried out only if cooperation is judged as "endangered" indicated by a total use s larger than η. High monitoring costs may motivate the group to tolerate a certain degree of overuse (in this case $n\lambda<\eta$). In the case the threshold is surpassed an order is given to an **external agency** to search for defectors.

Now in **our specific experimental setup** the game before monitoring is the usual game of the OGW-paradigm (formula (1) and c=5, f(s)=s(23-0.25s), n=8). Individual use is allowed up to the limit of λ=5. The monitoring agency is called for only in case of a total use larger than η=46. Monitoring imposes costs of 40. The division of monitoring costs and the flow of compensating fees are determined according to the following rules.

1. If some defection is detected, defectors have to bear monitoring costs and additionally to pay a compensating fee to everyone of their non-detected partners;
2. If no defection is detected the monitoring costs are distributed equally among the

commoners.

The external agent was implemented by a random mechanism with equal chances for all members to be controlled: two members out of the eight partners are drawn by chance for being inspected. The compensation fee was set to D=x-λ, the individual's take minus the limit („individual overuse").

Let z be the (n-1)-vector of the strategies of all partners (the sum of its components is y). Then the **payoff random variable** U(x,z,ω) for the above setting is of the form

(6) $U(x,z,\omega) = u(x,y) + t(x,z,K(s,\omega))$

The new term t represents **transfers** that depend on the **control events** h=K(s,ω). For the above **control technology** let h be the pair of inspected members respectively the event 0 where no control takes place (0= K(s,ω) iff s≤η). In case of no control t takes a value of 0. in case of control t=-5 iff no defector is detected.

In case of control there are three cases to distinguish (see table below): the detection of none, one or two defectors. Every detected deviator k has to compensate every partner that was not deviating or not detected by the payment of the individual overcrop D=x-5. The costs of control are paid by the detected deviators in equal parts.

number of detected deviators	t(x,z,{i,j})	
	detected deviator k: x>5 and k∈{i,j}	not deviating or not detected
0	-	-5
1	-40-7×(x-5) = 7D-40	(z_k-5)
2	-20-6×(x-5) = 6D-20	$(z_i-5)+(z_j-5)$

In order to calculate the best reply b(z) for some player P let us consider first the case of control with defection (x>5). If v is the number of partners that defect too, p=v/7 is the **probability to detect** a partner's defection under the condition that player P is detected. Since pairs of players are inspected with equal probability, the expected loss for P is

(7) $\text{loss} = 0.25(p(6D+20)+(1-p)(7D+40)) = 0.25(p(6x-10)+(1-p)(7x+5)) = \text{const} + (7-p)x/4$

Note that all other components of t, namely gains and the no-detection loss, are independent of x for the case of control. The first-order conditions for the **best reply** are

(8) $c = 23 - 0.5\,x - 0.25\,y$ in case of no control or no defection

(9) $c+(7-p)/4 = 23 - 0.5\,x - 0.25\,y$ in case of control and defection

There are no symmetric equilibria (p=0 and x=5, or p=1 and x>5). For example (9) and p=1 implies x=22/3 and y=51, but x=5 is payoff-superior.The only value for which (9) holds optimal is p=1/7: the optimal strategy is near 12 (exactly 82/7). This strategy gives rise to an equilibrium with two deviators using this strategy. The only other equilibrium can be derived by considering p=0 (and y=35). In this case (9) would imply x=15 and U=41.5. The no-control payoff u(11,35)=71.5 is superior.

Let us sum up: The game before monitoring is characterised by a *welfare optimum* of s=36 and a unique equilibrium x=8 (this corresponds to s=64). In the game including inspection there are two types of equilibria: the lower institutional equilibrium with exactly one deviator and the action profile (11,5,...,5) and the upper institutional equilibrium with exactly two deviators. Due to the integer-valued implementation the upper institutional equilibrium is approximated by the action profile (12,12,5,...,5). Both types of equilibria are asymmetric, inefficient but more efficient than the pre-monitoring equilibrium.

2.3 Experiment

Subjects get verbal and written **full information** on the payoff-structure and on the equal chance inspection. The group performs 20 rounds of the above game. During the game every subject gets private information on her or his payoff and public information on the actual total use s and on the inspection results. After the experiment subjects are payed (privately) according to their individual total payoff.

We refer to a series of 10 trials with 8 subjects and 20 rounds each. (Nine of these trials are carried out under standard conditions. The second trial deviates from these conditions in so far as the participants are staff members from economic laboratories in Karlsruhe and Saarbrücken and are not paid in money.)

trial	subjects	monetary payments
1	university students	0.02 DM / point
2	staff members	none
3	university students	0.02 DM / point
4	different occupations, different ages	0.02 DM / point + 20 DM for filling in a questionnaire
5	grammar school graduates (18yrs. old)	0.01 DM / point
6	grammar school graduates (18yrs. old)	0.01 DM / point
7	grammar school graduates (18yrs. old)	0.01 DM / point
8	grammar school students (14yrs. old)	0.005 DM / point
9	grammar school students (14yrs. old)	0.005 DM / point
10	grammar school students (14yrs. old)	0.005 DM / point

The following table shows the aggregate result and a characterisation of the different **use categories** for our scenario.

	total use	commons total f(s)-cs-t(s)	efficiency*	qualified as
no inspection	36	324	1.000	welfare optimum
	≤40	≥315	≥0.988	*permitted*
	≤46	≥299	≥0.923	*tolerated*
	46	299	0.923	lower institutional equilibrium
inspection	>46	<299-40**	<0.799	*inspection*
	54.39	248.06-40**	0.642	upper institutional equilibrium
	54	243-40**	0.627	upper institutional equilibrium, integer-rounded
	58.655	120.76	0.373	experimental mean
	64	128-40**	0.272	base line equilibrium**
	>72	<0-40**	-0.123	*ruin*
base line	64	128	0.395	base line equilibrium

*efficiency = commons total / welfare optimum; **costs of control t(s)=40

Columns above refer to no inspection, columns below to cases when inspection takes place. From the OGW-scenario we get the welfare optimum at 36, and the base-line equilibrium at 64. For the control mechanism considered and group size 8 we get two equilibria (rounded to integer values): a lower one without inspection and with one defection (total use of 46), and an upper one with inspection and two defections (total use of 54).

Note that compared to the equilibrium of the game without inspection (base-line) group performance is slightly better if measured by total use (overuse = 18.66), but it is slightly poorer if measured by payoff efficiency (.37 instead of .4). In comparison with the monitoring equilibria (overuse = 6 resp. 14) the cooperation shift is negative (except trial 5 and 6).

trial	1	2	3	4	5	6	7	8	9	10
efficiency	0.38	-0.22	0.17	0.58	0.75	0.67	0.53	0.32	0.52	0.36

Subjects do not succeed in adjusting to a **rational amount of offence**. At the individual level the **overcrop** D=x-λ is frequently much too small to pay potential losses if detected (mean = 5.98, this value is nearly what a single deviator should overcrop in the lower equilibrium; note that about 50% of the cases are at 4 or below).

individual overcrop pattern (entries: number of cases)

overcrop	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
cases	110	110	97	33	132	8	29	5	6	69	5	4	6	4	41	1	1	5	0	40

At the aggregate level the actual total overcrop is in eight of the ten runs significantly larger than for both types of equilibria (6 respectively 14). The unpaid staff members exhibit the largest overcrop. The secondary school graduates (trial 5-7) rank lowest in overcrop.

trial	1	2	3	4	5	6	7	8	9	10
mean group overcrop	22.25	40.80	25.65	17.35	10.05	12.90	17.00	22.45	19.30	23.40

3. Inefficiency and Stability

3.1 Oscillation patterns

The most astonishing observation may be that overcropping and total take oscillate without dampening or tendency to converge. For a more detailed analysis of the oscillation patterns it is useful to consider the frequency distribution of the **half-cycles**. Half-cycles are either upward movements or downward movements. They are characterised by their values in the two dimensions amplitude and half-cycle length (duration). In all trials we observed **oscillations** in total take that are very similar with respect to the average cycle length (mean=172:53.5=3.2 rounds; s.d.=0.56) and the average amplitude (mean=2037:107=19). Statistical tests (see Beckenkamp/Ostmann 1996b) reveal that the observed oscillation do not fit a chance move - noise model; a significant difference between cycling down and cycling up cannot be detected; there is no upward or downward trend in the timeseries as a whole, nor in amplitudes or cycling length.and that amplitudes have no tendency to decrease.

Oscillations in multi-variable systems may be generated by some kind of coordination of these variables. In our case we can think of coordination of decisions of different members. Those decisions are not coordinated within one period (because of the private nature of the decision). Indeed there is no significant correlation between the own decision x and the partners' total y (corr = 0.012, p=0.65).

The question is open: What processes can explain the observed, relatively stable oscillation pattern?

3.2 Regression models

A first explanatory model for what is going on is focused on the widely acknowledged importance of expectations and backward conjectures. Expected total use by partners, variableY, game-theoretically should be used to determine a best reply and socialpsychologically is expected to trigger social comparisons. For a best reply the **individual take x** and the **expectation Y** should be negatively related, for social comparison a positive correlation is to expect. Data yield a low negative correlation (corr = -0.130), but the regression of x on Y shows r^2 just being 0.018. Indeed a great deal of the individual actions are far from being best reply.

For a further analysis we define the **social comparison** variable a = x - Y/7. The variable a is called „advantage“. Indeed an individual may try to get an advantange of the „average partner“ by taking more than the average. Define D as a binary variable which represents **defection** (D = 1 iff x > 5). A clear separation of the two groups defections and non-defections can be found.

advantage	total	D=1	D=0
mean	**0.47**	**3.83**	**-2.28**
s.d.	*5.01*	*5.52*	*1.97*

Now a further step in the decision how much to take may be the decision to **leave** the common (x=0). The game-theoretic argument for a leave is an expected overuse (s>72, „crisis“). Let N be the binary variable representing the decision not to participate (N=1 iff x=0). A regression model yields

a=	6.29	- 0.18 Y	+ 5.83 D	- 4.25 N
s.d.	0.44	0.01	0.21	0.94
t-value	14.4	-20.3	28.4	-4.5
$r^2 = 0.556$		s.e. (res) = 3.34		

Up to now history does not matter explicitly. Scanning for reasonable candidates of lagged variables we found only one statistically reasonable candidate to add to the model: the own action yesterday x_{-1} plays a significant role in determining what has to be done today.

a=	5.37	- 0.18 Y	+ 5.34 D	- 5.09 N	+ 0.19 x_{-1}
s.d.	0.44	0.01	0.21	0.94	0.02
t-value	11.8	-20.7	26.4	-5.7	8.5
$r^2 = 0.590$			s.e. (res) = 2.76		

Let us ask what dynamic processes may generate such regression results. Considering first only the influence of the constant and the lagged action x_{-1} these components would lead the process to approach x=6.9. The only variable that can push up the amplitude is D, the decision to defect. This is why the decision to defect becomes central in the following considerations.

3.3 Cognition and simulations

Indeed in a second step let us investigate dynamic models that introduce a socio-cognitive dynamic for the variable D, the decision to defect. Here subjects may accumulate anger or claims that justify a defection from time to time. Unlike the rational model this would produce uncoordinated values of D for different members. Although we have indications for such a „katharsis"-mechanism, the moment, when to defect, is influenced by the evaluation of Y. **Simulation** models of this kind seem to show a reasonable fit to the observed oscillations (Beckenkamp/Ostmann 1996a):

Interacting actors are represented by agent units endowed with a state variable „charge" each. The agent unit is charged by accumulating motives or emotional causes to defect. Evaluation is represented by adding charge if the respective agent is being inspected, if it is to assume that there have been undetected defections, and if the agent unit is disadvantaged compared to the other units). Charge will be increased until above some threshold a discharge becomes possible. Models like those bridge the gap between explanations based on pure behavioural data and those that introduce tools of cognitive science.

In Beckenkamp/Ostmann 1996b it was argued that it is important to distinguish between cognitions and social cognition. The first one consists in **cognitions** refering to the environment and the second one in **social cognitions** refering to the group and group behaviour. The importance of the latter is widely discussed in social psychology: the role of common goals for the coherance and identity of a group has been emphasized. It may be that the introduction of sanctions has consequences with respect to this point, although there was no experimental manipulation of communication or visibility. „Responsibility" may be reduced if an external agency is seen in duty to guarantee prosperity. The struggling for advantages may become the focal social cognition. Besides the social cognitions the representations of the resource and of its formal properties are important to transform incentive structures into reasons to act. The evaluation of a situation as an „opportunity“ may be seen as cognition.

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