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KEEPING AN EYE ON YOUR NEIGHBORS: AGENTS MONITORING AND SANCTIONING ONE ANOTHER IN A COMMON-POOL RESOURCE ENVIRONMENT

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SOCIAL SCIENCE WORKING PAPER 1072

October 2000

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Abstract

The role of a specific institution in avoiding a "tragedy of the commons" situation in a common pool-resource environment is studied experimentally. The resource users privately decide their own exploitation level and then, once the group outcome is revealed, can choose to select other individuals for inspection. At a cost, the inspector can view the decision of any individual. If the inspected individual has exploited the resource excessively, relative to a publicly known amount, a fine is imposed and paid to the inspector. The rules, called *Carte di Regola*, were modeled after an historical case of self-governed rural communities. The impact of the rules is a dramatic increase in efficiency over the no rule case but still less than 100%.

As part of an attempt to understand the nature of the impact of the rules the paper focuses on models of individual agent's choices. The patterns of results relative to the classical Nash model are similar to other experiments. The model does well, except for the fact that contributions to the public good are less than Nash equilibrium amount. However, when the environment is changed to allow sanctions, contributions above the Nash equilibrium are observed. This paradoxical "flip" in behavior is explained by a non classical model in which spite plays a role in preferences and in which agents are heterogeneous. The model of asymmetric, other regarding agents also does relatively well in predicting patterns of individual choices such as the choice to inspect and sanction others. Efficiency is improved along with the strength of sanctions and the patterns of individual choices are consistent with the non classical model.

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INTRODUCTION*

The public choice and public economics literature has revealed many different fabrics of institutions applied to the management of social dilemma situations. This study provides some insights about the nature of decentralized enforcement of rules or customs in the sense that members of the society monitor one another's actions and implement sanctions in those cases in which the actions are deemed unacceptable. Several such institutions can be identified in the literature, which, on the surface, seem similar but close examination in light of theory suggests possibly dramatic differences in their impact on public performance. The broad questions posed by the study are related to the relative effectiveness and efficiency of the different forms that such institutions might take. Experiments are designed for a common-pool resource environment and the results are reported.

The general class of institutions is one in which individual actions can be monitored at a cost and then sanctions can be imposed if the actions are deemed inappropriate. For the most part the monitoring is decentralized or self-administered in the sense that the agents themselves have the capacity to observe or monitor the actions of other agents. The class of institutions has as a common purpose the enforcement of cooperation. However, the institutions differ according to the circumstances under which sanctions can be administered, the level of the sanctions and the possible rewards to those who do successful monitoring. The particular institution studied, motivated by a historical case of forest and pasture management in the Italian alps (Casari, 1997), will be called the

* The financial support of the National Science Foundation and the Laboratory of Experimental Economics and Political Science is gratefully acknowledged. We are also deeply appreciative of the collaboration of Stephen Van Hooser who developed the software program and helped extensively with the experiments. Many thanks to Anthony Kwasnica, Alvaro Gonzalez Staffa, Leslie Title, Roberto Weber, Angela Hung, and Peter Coughlan for their suggestions and help in running the experiments. Thanks also to William Morrison, David M. Messick, and Giangiacomo Bravo for the suggestions, James Walker for providing a copy of the instructions of their experiment, and to Robert Moir for his contribution to Table 1. This work has benefited from the comments of the participants at the 1999 ESA annual meeting, at a seminar at the University of Trento, Italy, and at the 2000 IASCP conference. The usual disclaimer applies.

Carte di Regola, taken from the name of the documents where the rules were written. No doubt, similar institutions can be found in many forms. For example, Varian (1990) reports the case of the Grameen Bank in Bangladesh, where potential borrowers mutually monitor each others projects to ensure the success of the financed enterprise. Field accounts of sanction systems in common-pool resource management can be found in Bromley (1992).

Laboratory methods have been applied many times to gain a better understanding of the complex social arrangements that might be useful as environmental safeguards. In the light of previous experimental work the aim of the paper is twofold. The first is to study the robustness of the results reported in an important experimental contribution by Walker, Gardner and Ostrom (WGO, 1990). The phenomena they report from common-pool resource experiments without sanctions exhibit a type of inconsistency with public goods experiments that we will call "the spite/altruist paradox". The inconsistency invites replication and further investigation.

The second purpose of this paper is to study the influence of the self-financed monitoring and sanctioning institution represented by the *Carte di Regola.* The question posed is related to its influence on the efficiency of resource use. The economic environments implemented in the experiments are reviewed in Section 2. The spite/altruist paradox that motivates part of the study is introduced in Section 3. Experimental procedures are outlined in Section 4. Theory and the productions of the two major models are outlined in Section 5 and Section 6. Predictions from the models for the various treatments, including designs with and without sanctions, are outlined. The results of experiments without sanctions are presented in Section 7 followed by the results of experiments with sanctions in Section 8 and Section 9. The conclusions follow in Section 10.

2. THE ECONOMIC ENVIRONMENT

The environment consists of a group of agents where each agent i=1,..,N chooses her individual use level, x_i, of a common-pool resource between a lower limit of zero (i.e. not using the common-pool resource) and a given upper limit $\hat{x}$. Using the resource involves a costly effort that is captured by the linear cost variable v. The payoff of agent i, π_i, is:

$$\pi_i = v \cdot (E_i - x_i) + \frac{x_i}{X} \cdot f(X) \qquad \textit{where } X = \textstyle\sum_{i=1,\dots,N} x_i \textit{ and } x_i \in [0, \hat{x}] \textit{ with } i=1,\dots, N \qquad (1)$$

Aside from the parameters in the function $f(X)$, which yields the total flow of revenues from the common-pool resource, the only parameters of the problem are the endowment E_i and the cost variable *v*. In a sense the variable *v* can be viewed as the opportunity cost given by the returns to investments in some sort of private activity instead than in the common-pool resource. For instance, a peasant can earn a fixed salary as an employee, or raise his own cattle on the common pasture, or allocate part of his time to both activities. The endowment E_i determines the earnings of the subject when she chooses not to use the common-pool resource. Within each experiment it will be the same across all agents.[1]

< ***Figure 1 about here*** >

The group revenues *f(X)* increase in X up to a maximal point and then decrease. What matters to the group are the revenues once the opportunity cost of the alternative activity is subtracted, $\Pi = f(X) - vX$. The payoff of agent *i*, π_i , can be depicted as her share of Π, and this share is proportional to her individual use relative to the group ($\frac{x_i}{X}$).

As is well known, without proper incentives the use of the common pool resource can result in the "tragedy of the commons" (Hardin, 1968). Figure 1 illustrates this idea. If the group use is at the socially optimal level, X_0, an agent has an incentive to change action. The earnings of an individual increase as her level of x_i increases because the individual appropriates a larger share of Π. This action imposes a negative externality on the group because Π becomes smaller than before. A fisherman who over-fishes today, for instance, will reduce the tomorrow's catch for him and for his peers. The unstructured interaction of N self-interested agents will lead to an excessive use of the common resource[2]. This general framework models many situations such as the exploitation of renewable resource, the use of a shared central computer, and the Cournot competition in an oligopoly[3].

3. THE SPITE/ALTRUIST PARADOX AND SANCTIONING SYSTEMS

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[1] The two variables E (endowment) and $\hat{x}$ (upper limit in the individual use of the common-pool resource) can be modified independently. In the WGO(1990) design a change in E necessarily affected $\hat{x}$.

[2] As a terminology clarification, a free rider will *over*-use a common-pool resource while *under*-contribute in a public good provision situation.

[3] The payoff π_i could be seen as the profits of an oligopolistic firm i that decides the quantity of goods x_i to produce and sell on the market. If we assume that the market demand is a linear function $D = a - b \cdot X$ and the technology has constant returns to scale, i.e. the cost to produce a unit of the good is always v ($E = 0$), then the total revenues in the market are $f(X) = a \cdot X - b \cdot X^2$ and the share of the revenues that goes to firm i is proportional to its market share x_i / X.

This study is designed both to test the replicability of results reported in the literature and, especially, to analyze the effects of a specific self-managed monitoring and sanctioning mechanism in a common-pool resource environment. The need for a test of replicability and robustness of results in the literature follows from some perplexing results summarized below. To this end a baseline experiment is conducted with no sanctions. The parameters implemented for the baseline experiment are similar to those used in other studies and were taken – with some adjustments – from the experimental study by Walker, Gardner, and Ostrom, 1990 (WGO). The results they report from a sanction-free environment can be summarized in two points[4]:

(1) The agents heavily over-use the resource at levels that go beyond what a pure free-riding behavior would suggest;[5]

(2) The pattern of individual use levels does not stabilize at the one-shot Nash equilibrium

These results are puzzling because in voluntary contributions public goods experiments agents frequently exhibit cooperation levels in excess of the Nash equilibrium prediction (Andreoni, 1995 and Isaac, Walker and Williams, 1994) while WGO reports that in common-pool resource experiments the cooperation level is below it. Because cooperation above Nash can be interpreted as altruism and cooperation below Nash can be interpreted as spite, this phenomenon will be labeled the "spite/ altruist paradox".

This paradox emerging from the WGO experiments presented a challenge to not only replicate their experiments but also to explore the robustness of the results they report. Several methodological and procedural changes were introduced in the experiments that we report. The monetary incentives were increased compared to the original study, by reducing the minimum safe earning and raising four times the conversion rate between laboratory currency and dollars. The instructions were rewritten and special software developed. Other parameter adjustments were made to facilitate the understanding of the experiment by the subjects, such as re-scaling the action space. A complete list of changes is included in Appendix A.

[4] Conclusion 2 is an interpretation given in Ostrom et al, 1994, p.117.In their study there is a third conclusion: the total group appropriation exhibits a pulsing pattern across periods. Appropriation levels decayed and then rebounded repeatedly in the same experiment. A similar phenomenon was reported in Isaac, McCue and Plott (1985). When the idea of 'pulsing patterns' is operationalized into precise indexes, we find systematically lower values in our no sanction experiments compared to theirs. Having said that, we don't have any benchmark to state that our results did or did not exhibit pulsing patterns.

[5] The excessive use efforts were particularly impressive when the maximum potential effort of the agents, N$\underline{x}$, was very high in relation to the Nash equilibrium use level (about three times as much). Recall that $\hat{x}$ is the upper limit on x_i, and was the same for all agents. Walker, Gardner, and Ostrom (1990) test two designs with different ratios of Nash

While the spite/altruist paradox is important, the primary focus on this study is on a special institutional arrangement for guiding decisions regarding common-pool resources called the *Carte di Regola* . The *Carte di Regola* was part of the organization of rural communities in a mountain region of Northern Italy, where a sanctioning mechanism was in place to limit overexploitation of the village forests and pastures (Casari, 1997). The *Carte di Regola* institutions survived for more than six centuries. Both the conditions under which a sanction could be inflicted and the amount of the fine were specified in advance in written documents. The village court would sentence people who used the common resource above an established limit to pay a fine proportional to the severity of the damage inflicted to the community. A share of such fine usually went to the prosecutor. Any villager could report a violation but he usually incurred a cost in the form of a monitoring effort to discover the free rider and additional costs to bring him to court.

Formal sanctioning systems are often adopted by groups to keep the excessive use of a common resource under control (Ostrom, 1990). Table 1 offers a detailed break down of the features of monitoring and sanctioning institutions and illustrates the characteristics of the specific institutions studied in the experimental literature. In most systems the group outcome is common knowledge and monitoring enables the agents to observe the individual actions of other agents. An inspection involves both a monitoring action and a sanctioning action. Sanctioning enables an agent to reduce the payoff of other group members who deviate from agreed upon rules of behavior. Systems typically studied in the literature are defined by the following two features. First, the action of punishing is a loss for both the person who inflicts it and for the one targeted by it. Sanctions constitute a *complete* deadweight loss for the group. Secondly, the more an agent is willing to pay for sanctioning the harsher the punishment inflicted. An example is the damage that a member of a village inflicts overnight to the nets of a fellow fisherman.

< ***Table 1 about here*** >

Some notation is needed to facilitate the comparison of the experimental designs and results that are found in the literature. A sanction system is characterized by a reward parameter ϑ, that measures the amount of punishment inflicted (s) relative to the cost to request a sanction (c, $\vartheta \equiv s/c$,

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equilibrium over the endowment. In the high endowment case (the one that we have replicated here, $\hat{x}=50$) the ratio is 0.32 and in the other case (with $\hat{x}=20$) is 0.64.

where c, s > 0. The three studies of self-administered sanctions found in the literature (Ostrom at al, 1994; Moir, 1998; Fehr and Gatcher, 1999) have the following common results[6]:

(1) Agents do request sanctions. The agent who requests a sanction will incur in a loss because c>0 and such behavior is incompatible with purely self-interested motives according to one-stage Nash strategies.[7]

(2) The lower the reward ϑ from sanctioning, the less frequent sanctions are requested. Agents are responsive to the cost of sanctioning and to the magnitude of the impact of sanctions on other people's earnings.

(3) Gross group earnings (or rent) Π increase. Free riding behavior is more often targeted than cooperative behavior.[8]

(4) Net group earnings do not always increase. Net group earnings comes from gross group earnings Π minus the sanctioning fees c. Ostrom et al (1994) report a net loss while Moir (1998) and Fehr and Gratchen (1999) find a slight gain.

The *Carte di Regola* sanction system presents two fundamental differences with the other sanction systems:

- The punishment (s) is a transfer of money from the targeted agent to the inspector. Hence inspecting is profitable when the fine is higher than the sanctioning fee (c), which remains a deadweight loss for the group.
- The punishment needs to fit the crime and does not depend upon the will of the inspector. In the specific case, the agent inspected pays a fine only if he used more than a publicly known level and the fine is proportional to his excessive use.

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[6] Other studies have been not included in the review either because they have an external sanctioning authority (Beckenkamp and Ostmann, 1999, Cardenas et al, 1999) or because the experimental design is for other reasons too different from ours (Yamagishi, 1988; McCusker and Carnevale, 1995). Experiments with external sanctioning authorities reports a less succesful story in raising group efficiency. The authors attributes at least part of the modest performances to the psychological distance between the users and the sanctioning authority.

[7] In a social sanction system the best action of a self-interested agent is not to request sanctions at all. Experimentally, the use of sanctions might simply be the result of a trembling hand behavior or plain confusion. As it will become clear, in the *Carte di Regola* sanction system the equilibrium can be moved away from the border of the action space.

[8] Why are free riders more often targeted than cooperators? Because targeting free riders is oftentimes more rewarding than targeting cooperators. Of course this feature depends upon the experimental design. While this assumption is correct for this study and for Fehr and Gatcher (1999) (although they do not spell out this point) it is not for Ostrom et al (1994) and Moir(1998). For more on this point see discussion in the conclusions.

There are two additional features of the *Carte di Regola* that are different from the sanctioning systems found in other studies. An agent can be convicted only once for the same violation. In other words, there is no cumulating of sanctions that are requested by different agents on the same action. An inspection involves at the same time information discovery as well as punishment. Secondly, the individual actions are unknown before requesting the inspection: monitoring and sanctioning occur at the same time[9].

4. EXPERIMENTAL PROCEDURES

A total of 56 subjects were recruited from the campus of the California Institute of Technology for a total of 10 experimental sessions. The different treatments are outlined in Table 2. There are three different sanctioning designs: No Sanction, Weak Sanction, and Strong Sanction and two different levels of subject experience with common-pool resource experiments: Inexperienced and Experienced. In the sanction treatments any subject has the option of selecting other individuals for inspection after she has privately decided her own exploitation level. At a cost, the inspector can view the decision of any individual. If the inspected individual has exploited the resource excessively, relative to a publicly known amount, a fine is imposed and paid to the inspector. In the strong sanction design the unitary fine is four times higher than in the weak sanction treatment and the definition of excessive resource use is stricter. Within each treatment, half of the experiments were conducted with inexperienced subjects and the other half with experienced subjects.

< *Table 2 about here* >

There were 8 subjects in each experimental session. All subjects were seated at terminals, separated by partitions, and assigned identification numbers. No communication was allowed. Instructions were read aloud to everyone (instructions are reported in Appendix B). The experiments were run on networked personal computers using dedicated software for Netscape.

Each subject faced a decision about the level of effort to put in the appropriation of a common-pool resource (or, simply, in the *use* of the resource), where that effort had a linear cost and the resource yielded non-linear revenues. The use level ranged from zero to a maximum level and was

[9] In the simplified version for the laboratory, the inspection fee is the analogous of procedural costs in the *Carte di Regola* system and the entire fine is transferred to the prosecutor. In our experiment, the verdict of the court is always supposed to be correct and the identity of the prosecutors is not revealed. Moreover, there is no communication face to face.

chosen without knowing the choices of the other subjects. Use levels were expressed in " tokens" and payoffs were in terms of "francs" (an artificial laboratory currency with a publicly known dollar-exchange rate) and in dollars. A constant unitary cost was charged to the subjects for every token used as an opportunity cost for the appropriation effort. The *gross group return* $f(X)$ from the market depended in a non-linear fashion on the sum of the uses X of all the subjects and was first increasing and than decreasing in X. The individual return consisted of a share of the total group return corresponding to the fraction of the individual use x_i on the group use X.

Each subject was paid privately in cash immediately following the experiment. An experiment lasted from 1 hour to 2 hours and 20 minutes including the preliminaries (instructions, questions and answers, quiz, and practice rounds). Individual earnings ranged from $5.80 to $53.10.

An experiment consisted of a number of periods from 27 to 33 and each period consisted of just one step in the no sanction treatment and of two steps in the sanctioning treatments. During step one, the computer screen prompted a request for a number of tokens that the subject wished to put in the market. A subject could digit any real number between 0 and 50. After everybody completed the input, the software displayed the group outcome (total group use and gross group return). At this point, in the no sanction treatment subjects could also see their individual period payoff (your share of gross, cost of tokens, period payoff), while in the sanctioning treatments this part was postponed until the end of step two. Step two gave a chance to inspect other subjects. By clicking on a box next to the subject identification number, a subject could ask to uncover the use level of any number of subjects from 0 to 7. A fee was charged for every inspection and the eventual fines collected were credited to the inspectors. After everybody had taken this decision, the period results were displayed.

The period payoff was computed and explained in terms of its three components: result of use decisions, result of inspections asked, and notices of the eventual charge for an inspection targeting the subject. In case more than one subject asked to inspect the same person, a random device would pick only one inspector and cancel the requests of the others. At this point, the use level of the subjects inspected during that period became public information. The software was designed in a way that a history record of the decisions always appeared on the computer screen. Subjects could see their past individual uses, their individual cumulative payoff, the past total group uses, the past gross group returns, and the past uncovered use levels of subjects inspected.

To ensure that the rules were well understood we adopted the following procedure. First, the rules were publicly explained in detail and with examples. Second, a quiz was given. All the correct answers were read aloud after completion of the quiz and the ones where mistakes were noticed in the answers were further explained. Third, two practice periods were run, to help the subjects familiarize themselves with the rules of the experiment and with the software. After the two practice rounds, a number of periods from 27 to 33 were run. Subjects were not told the number of rounds that were to take place. At the end of the third-before-the-last period, an announcement was made that the experiment was going to end in two periods. After the experiment was over, a questionnaire was submitted to the subjects asking for the strategy they followed.

5. CLASSICAL MODEL

In this section we compute the Nash equilibrium of the model under the three sanction designs – no sanctions, weak sanctions, strong sanctions - using a standard model of homogeneous, self-interested agents. We will refer to it as the classical model. We assume that the agents are risk neutral and that the preferences of all the agents are common knowledge.

5.1. NO-SANCTION DESIGN

The payoff function of a self-interested agent *i* in the no-sanction design is:

$$\pi_i = v\cdot(e - x_i) + \frac{x_i}{X}\cdot(aX - bX^2) \quad \text{where} \quad X = \Sigma_i\, x_i \quad \text{is the group use} \qquad (1')$$

The best response function is a linear function of the use level of everybody else (Figure 2),

$$x_{-i} = \sum_{j\neq i}^{N} x_j : \qquad x_i^* = \frac{a-v}{2b} - \frac{1}{2}x_{-i} \qquad \text{where } x_i^* \text{ is bounded to be in } [0, 50] \qquad (2)$$

The efficiency of an outcome is defined by its corresponding group earnings relative to the maximum theoretical group earnings. Efficiency is 100% at the socially optimal level and 0% at the open access level. In an open access situation the resource is available for the use of anybody and the equilibrium is computed as the use in the limit when the number of appropriators goes to infinity. The Nash equilibrium value for a group of N agents is in-between the social optimal and the open access levels (see Figure 1 for an illustration). To use a market analogy, the three situations correspond to a monopoly, Cournot oligopoly, and perfect competition situation.

< ***Figure 2 about here*** >

Proposition 1A. (*RESOURCE USE EFFICIENCY WITHOUT SANCTIONS*)

Under the parameters of the experiment without a sanctioning institution, the Nash equilibrium outcome with homogeneous, self-interested agents has an efficiency of 39.5% of the optimal level [X=128].

All the agents will use the resource at an identical rate of 16 tokens.

When agents are identical, the Nash equilibrium outcome is $x_i = \frac{a-v}{(N+1)b} \forall i = 1,...,N$ that - given the parameter values N=8, a=23/2, v=2.5, b=1/16 - corresponds to an individual use of x_i=16 and to a total group use of X=128. The socially optimal outcome is at X=72 and could be obtained if all the eight agents in the group choose 9 tokens. The efficiency of the Nash equilibrium is 39.5% with reference to the maximum potential earnings Π=324 (where the endowment is set to zero, E=0). At the open access use level of X=144 (x_i=18) the net group return is equal to just the period endowment, which implies a complete destruction of the potentially positive incomes that the group could have made out of the common-pool resource (Π=0).

5.2. WEAK SANCTION DESIGN

In the sanction treatments each period has a use and an inspection phases. Once the total group use is revealed, agent *i* might ask to inspect any other agent *j* (I_{ij}=1 when an inspection is requested, I_{ij}=0 otherwise, $i \neq j$). Agent *i* pays a fee k for every inspection carried out and a transfer s_j from agent *j* to agent *i* is made. The transfer s_j is proportional to the use of agent *j* in excess of a threshold of λ tokens. The total revenues from inspections for agent *i* are $r_i = \sum_{j=1}^{N} I_{ij} r_{ij}$, where:

$$r_{ij} = s_j - k \quad \text{and} \quad s_j = \begin{cases} 0 & , x_j \leq \lambda \\ h \cdot (x_j - \lambda) & , x_j > \lambda \end{cases}$$

The parameter h is the unitary fine for each extra token used and measures the stiffness of the punishment. Sanctions modify the incentives for use because they threat to increase the cost of using the common-pool resource above a given limit of λ tokens. In Figure 2, sanctions would induce a downward shift in the best response function of a targeted agent. The degree of the shift depends on the perceived probability p_i that an agent has of being inspected. If such probability is zero for all the agents, the incentive structure is identical to the no sanction one but if it is strictly positive for some agent, her best response is to use the resource less than in the corresponding no inspection case:

$$x_i{}^* = \frac{a - v - h\,p_i}{2b} - \frac{1}{2}x_{-i} \qquad , \quad if \quad x_i \geq \lambda \qquad (4)$$

Proposition 2A. (*RESOURCE USE EFFICIENCY WITH WEAK SANCTIONS*)

When agents are homogeneous and self-interested, the introduction of weak sanctions will not change the classical Nash equilibrium level stated in proposition 1A (because no sanction will be requested).

Proposition 3A. (*INSPECTION BEHAVIOR WITH WEAK SANCTIONS*)

When weak sanctions are introduced, at the Nash equilibrium inspections pay zero and thus agents are indifferent. However, if a slight psychological cost exists no inspection will be requested by homogeneous, self-interested agents.

When weak sanctions are in place (k=7, λ=9, h=1), the symmetric Nash equilibrium in the resource use phase and in the inspection phase ranges in $X^*\in$ [113.7, 128] - or equivalently $x_i^*\in$[14.2, 16] - depending on the probability of agent j of being inspected p_j. What determines p_j ?. Agent i will inspect another agent j if it is profitable to do so, $r_{ij} > 0$, and this situation occurs when the use level of agent j is high enough to generate a sufficiently large sanction to cover the inspection fee k=7, *i*.e. $x_j > \frac{k}{h} + \lambda$ =16.

It is important to note that weak sanctions have no effect on group outcomes. That is, if all agents are identical and self-interested and if that fact is common knowledge, then the total group use will not change from the no sanction design level and there will be no inspection. In other words, the classical Nash equilibrium outcome is (X*, p*)=(128, 0) because no inspection will be profitable as long as X≤128 and agents are symmetric (p_i=p $\forall i$). As stated in proposition 1A, in equilibrium agents have no incentive to use the resource more than X=128 even without the possibility of sanctioning. When X>128 the inspection of each one of the agents will be profitable. The number of requests to inspect agents will be zero before X=128 and jump to N(N-1) (i.e. 56 for N=8) after that point..[10]

[10] The equilibrium X*=128, p*=0 is slightly altered when the agents have a "trembling hand" in their inspecting decisions. If a subject inspects "by accident" and this kind of events is common knowledge the equilibrium will be below X=128. We believe that this point affects neither our basic results nor our conclusions.

5.3. STRONG SANCTION DESIGN

The weak sanction design described above does not alter the equilibrium outcome of the no sanction design. The inspecting device simply puts stronger incentives to discourage over-use, which is not in the agents' self interest anyway. On the contrary, the strong sanction design has the explicit purpose to move the equilibrium away from the inefficient equilibrium of the no sanction treatment to an efficient equilibrium.

> **Proposition 4A** (*RESOURCE USE EFFICIENCY WITH STRONG SANCTIONS*)
> When agents are homogeneous and self-interested, the introduction of strong sanctions will move the Nash equilibrium outcome very close to the socially optimal level [above 99% efficiency, X=71.1].

> **Proposition 5A**. (*INSPECTION BEHAVIOR WITH STRONG SANCTIONS*)
> When strong sanctions are introduced, all agents will inspect everybody.

There are many ways to modify the inspection parameters k, h, λ in order to move the equilibrium to the socially optimal point of X=72. The inspection fee is a technological parameter that represents ideally the degree of difficulty in observing other people's actions and was not changed (k=7). Instead the institutional parameters h and λ were adjusted, by inflicting stronger punishments for violations of stricter individual quotas (h =4, λ=7).

For the new set of parameters, the equilibrium group use ranges in $X^* \in$ [71.1, 128] - or equivalently $x_i^* \in$[8.9, 16] - depending on the inspection probability p. Inspecting an agent is profitable when x_i> 8.75. If agents are symmetric, no inspection will be profitable unless X>70. In the new symmetric equilibrium (X*, p*)=(71.1, 1) all the agents are inspected and the group efficiency is at 99.97%. The total group use X* is slightly lower than the social optimal value in order to assign integer numbers to the parameter values to facilitate the agents in the computations. The difference in terms of efficiency is, however, negligible.

6. A MODEL WITH HETEROGENEOUS, OTHER-REGARDING AGENTS

In this section we outline a simple model where an agent's payoff depends not only on personal earnings but also on the earnings of the other people in the group and then compute the Nash equilibrium of the model. This class of models appears both in some of the early texts of the classical and marginalist schools (Smith, 1759; Edgeworth, 1881) and in more recent experimental works (Krebs, 1970; Rabin, 1993; Ito et al, 1995; Chan et al, 1997; Levine, 1997; Bolton and Ockenfels, 1999; Saijo, 2000; Fehr and Schmidt, in press;). The recent, growing interest in these models stems from a realization that " pure self interest is clearly not a fully adequate description of human motivation. Realism suggests that economists should move away from the presumption that people are motivated *solely* by self interest" (Rabin, 1996). Rabin (1996) cites an extensive body of experimental research where people exhibit pattern of not self-interested behavior.

The specific shape of other-regarding preferences presented in this section intends to capture in a parsimonious way a component that is believed to motivate human behavior.

MODEL WITH HETEROGENEOUS, OTHER-REGARDING AGENTS

$$U_i(\pi_i, \Pi_{-i}) = \pi_i + \gamma_i \Pi_{-i} \qquad (3) \qquad \begin{cases} \gamma_i > 0 & \text{Altruistic agent} \\ \gamma_i = 0 & \text{Self-interested agent} \\ \gamma_i < 0 & \text{Spiteful agent} \end{cases} \qquad \Pi_{-i} = \Sigma_{j \neq i} \pi_j \quad \gamma_i \in [-1, +1]$$

Self-interest is a special case of the model ($\gamma_i = 0$). In general, agent *i* is willing to give up \$1 of personal earnings (π_i) in order to see the other people's earnings (Π_{-i}) changed by $1/\gamma_i$ dollars. A positive value in the other-regarding parameter γ_i denotes an altruistic attitude toward the group, while a negative value denotes a spiteful attitude. *A spiteful agent will find enjoyment in decreasing the earnings of others* and therefore she is willing to use some of her personal earnings in order for that to happen. The degree of altruism or spite is bounded in a way that nobody will choose to pay more than \$1 to modify the group earnings by less than \$1. Although not crucial for the conclusions, we think that this assumption of $\gamma_i \in [-1, +1]$ is reasonable. The definition of spite we have given is similar to the one adopted by Levine (1997) and Saijo (2000) but different to the concept of envy suggested by Mui (1995). The model (3) does not incorporate any reciprocity nor equity nor fairness considerations.

Agents in a group are assumed in general to be heterogeneous. In other words, the agents are assumed to care about others' earnings to different degrees γ_i and, in particular, groups are assumed to have at least two agents *i*, k that are different, $\gamma_k \neq \gamma_i$. As in the classical model, agents are assumed to be risk neutral and the preferences of all the agents common knowledge. Expression (3) is referred as the model with heterogeneous, other-regarding agents.

The remaining of this section is devoted to the computation of the Nash equilibrium in the three designs[11]. The payoff function for agent *i* in the no sanction design is now:

$$\pi_i = v\cdot(e - x_i) + \frac{x_i}{X} \cdot (aX - bX^2) + \gamma_i \left[v\cdot((N\text{-}1)e - X_{-i}) + \frac{X_{-i}}{X} \cdot (aX - bX^2) \right] \qquad (1'')$$

where $X=\Sigma_i x_i$, $X_{-i}=\Sigma_{j\neq i} x_j$. The best response function is:

$$x_i{*} = \frac{a-v}{2b} - \frac{(1+\gamma_i)}{2} x_{-i} \quad \text{, where } x_i\text{* is bounded to be in [0, 50].} \qquad (2'')$$

Proposition 1B. (*RESOURCE USE EFFICIENCY WITHOUT SANCTIONS*)

Without a sanctioning institution the Nash equilibrium with heterogeneous, other-regarding agents depends upon the preference structure of the agents. For instance:

- When *all* agents are altruistic, group efficiency will be better than the classical Nash.
- When *all* agents are spiteful, group efficiency will be worse than the classical Nash.

In general, individual agents will use the resource at a different rates, with spiteful agents using it more than altruistic agents.

In the no sanction environment (N=8, a=23/2, v=2.5, b=1/16), The *symmetric* Nash equilibria of the model range in $X^*\in[72, 400]$ that corresponds to an efficiency interval [–321%, 100%] depending on the value of the other-regarding parameter vector γ. For illustrative purposes, if all agents are homogeneous and altruistic with γ_i =1/7 then the Nash equilibrium is X*=115.2, while if they are all identically spiteful with γ_i = - 1/7, then X*=144 [12]. With heterogeneous preferences the

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[11] To simplify computation, we assume that the vector of other-regarding parameters γ is such that the *individual* response function is within the interval $x_i\in[0,50]$. This assumption might further restrict the range of γ to a subset of the [-1, +1] interval.

[12] With all self-interested agents γ_i =0 the outcome is the same as in the classical model, namely X*=128. If all the agents are homogeneous, the group appropriation level with other-regarding agents is X*=72 with completly altruistic agents (γ_i = 1) and is X*=400 with completely spiteful agents (γ_i =- 1). The model has of course also asymmetric Nash equilibria, which depend upon the individual preferences within the group. For instance, when half of the agents are altruistic γ_i =1/7 and half are spiteful γ_i = - 1/7 (symmetrically heterogeneous preferences) the group outcome is X*=126 and the individual appropriation levels will be x_i =0 and x_i =31.5 respectively.
An interesting case is when the preferences in the group are symmetrically heterogeneous or, in other words, for every altruistic agent *i* with γ_i >0 there is a spiteful agent *k* with γ_k=- γ_i . The Nash equilibrium with symmetrically heterogeneous agents is in general more efficient than the classical Nash equilibrium (39.5%).

outcome is still in the range indicated above but there is no longer a one-to-one correspondence between a group outcome X* and a unique vector of agent preferences.

With heterogeneous preferences also the individual use levels are heterogeneous. In particular, the lower the other-regarding parameter γ_i, the higher the individual use x_i is: spiteful agents use the resource more than self-interested agents and self-interested agents use it more than altruistic ones.

Proposition 2B. (*RESOURCE USE EFFICIENCY WITH WEAK SANCTIONS*)
When agents are heterogeneous and other-regarding, the introduction of weak sanctions will improve upon the Nash equilibrium level without sanctions stated in proposition 1B.
If two or more agents are not altruistic (sufficient condition), the improvement will be strict and inequality in the individual use of the resource will decrease relative to the no sanction design.

When a group is heterogeneous and other-regarding, agents use the resource at different rates (proposition 1B) and in particular at least one non-altruistic agent uses the resource above $x_i=16$. If there are two or more non-altruistic agents, that action will be inspected when information is perfect. This threat being sanctioned gives an incentive to lower the use level of the resource. As a consequence, the group use rate decreases and the welfare improves compare to the no-sanction environment.

Under the threat of sanctions, the best response function of an agent *i* with other-regarding preferences is:

$$x_i^* = \frac{a - v - p(1+\gamma_i)h}{2b} - \frac{(1+\gamma_i)}{2} x_{-i} \quad , \text{ if } x_j > \lambda \qquad (4')$$

Spiteful agents are particularly sensitive to the threat of sanctions because the money that is taken away from them is given to somebody else while altruistic agents care less about sanctions precisely because of this fact. Sanctions induce spiteful agents to lower their use level proportionally more than altruistic agents. In particular in the weak sanction design ($h=1$, $\lambda=9$, $k=7$), the inequalities in use levels within the group will be reduced, although spiteful agents will still use the resource more than altruistic agents will.[13]

Proposition 3B. (*INSPECTION BEHAVIOR WITH WEAK SANCTIONS*)

[13] Individual earning inequalities from resource use (excluding revenues from the inspection activity) will also decrease in the periods where the earnings of the group are non-negative, $f(X)\text{-}vX=0$ (i.e. $X \leq 144$).

When weak sanctions are introduced,

(i) There will be a positive number of inspections if two or more agents are not altruistic (sufficient condition)

(ii) The heavier users (the most spiteful agents) will be more aggressive inspectors than lighter users (the most altruistic agents) and will also purposively request non-profitable inspections.

Agent *i* will inspect agent *j* when both $x_j > \frac{k}{h\,(1-\gamma_i)} + \lambda$ and $x_j > \lambda$[14]. Inspection decisions are affected by the value of the other-regarding parameter γ_i . In particular a spiteful agent *i* inspects for lower values of x_j than an altruistic agent does. The reason is that she finds enjoyment not only from the cash flow of the fine but also from decreasing the income of some other agent. On the other hand, an altruistic agent is concerned about the social loss constituted by the inspection fee *k* and does not consider all the money of the fine s_i as a gain since it has been subtracted from somebody else she cares about. For instance, in the weak sanction treatment, a moderately spiteful agent with γ_i =-1/7 will request an inspection for any x_j>15.1 (and lose money if x_j<16) compared to a self-interested agent who would do it only when x_j>16. A moderately altruistic agent with γ_i =1/7 would inspect only agents with x_j>17.2. A completely altruistic agent (γ_i =1) will never inspect, while a complete spiteful one inspects when x_j>12.5. An implication of this examination is that when facing the same use pattern, high users will be more aggressive inspectors than low users will.

The situation for unprofitable inspections can be reformulated using the terminology introduced in section 3. The cost for the inspector is $c=k-s$ and the damage inflicted is s. So in our other-regarding model agent *j* will request the inspection if $\vartheta < -\gamma_j$, where $\vartheta = s/c$.

Proposition 4B. (*RESOURCE USE EFFICIENCY WITH STRONG SANCTIONS*)

When agents are heterogeneous and other-regarding, the introduction of strong sanctions will shift the Nash equilibrium at an efficiency level above 98% of the socially optimal level under some regularity conditions on preferences ($X \in [64, 72]$).

Proposition 5B. (*INSPECTION BEHAVIOR WITH STRONG SANCTIONS*)

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[14] The payoff function of agent i when he can inflict a sanction on agent *j* is $U^{\wedge}_i(\pi_i, \Pi_{-i}) = U(\pi_i, \Pi_{-i}) + (s_j - k) - \gamma_i s_j$. The decision is to inspect when U^>U, or $(s_j - k) > \gamma_i s_j$,

(i) When strong sanctions are introduced, all agents will be inspected under some regularity conditions on preferences

(ii) Lighter users (the most spiteful agents) will be more aggressive inspectors than heavier users (the most altruistic agents).

In a strong sanction environment (k=7, λ=7, h=4), the symmetric Nash equilibrium outcome is in the range $X^* \in [64, 72]$ - or equivalently $x_i^* \in [8, 9]$ – when the probability of being inspected p is set equal to 1. If all agents are completely altruistic (γ_i =1) the outcome will be socially optimal (X=72, 100% efficiency) while if all agents are completely spiteful (γ_i =-1) the outcome will be 98.77% efficient (X=64).

In equilibrium the probability of agent j being inspected p_j, is actually equal to one, under some regularity conditions on preferences. A completely altruistic agent (γ_i =1) will never inspect while a complete spiteful one inspects when x_j>7.9. A sufficient condition on group preferences for all actions to be inspected is that there are two or more non-altruistic agents and that the most spiteful one is "not too far apart" from the next. More formally, when agents are ranked low to high other regarding parameters $\gamma_{(1)}, \gamma_{(2)}, \ldots, \gamma_{(8)}$, then $\gamma_{(1)}, \gamma_{(2)} \leq 0$ and $|\gamma_{(1)} - \gamma_{(2)}| < 0.25$.[15]

In the weak sanction treatment spiteful agents still use more in absolute terms than altruistic agents while with strong sanctions, the situation is reversed because of the stiffness of the sanctions: the higher users are relatively more altruistic than the lower users. According to the heterogeneous, other-regarding agent model, the lowest users will be more aggressive inspectors than the highest users will.

7. RESULTS OF NO SANCTION EXPERIMENTS

The experimental results are compared with the predictions of the classical model (1A) and of the heterogeneous, other-regarding agent model (1B). The data demonstrate that the predictions of the classical model in the no sanction environment are subject to systematic errors. The other-regarding agent model does better.

[15] This condition is satisfied in three of the four no sanction experiments. The April 7 experiment satisfies a different sufficient condition: No agent is very spiteful (γ_i>0.45 $\forall$i) and at least two agents are not altruistic ($\exists$ i,j : γ_i ,$\gamma_i \leq 0$). The above statements are based on the estimation describe in Paragraph 7 point (f).

Result 1A. Without a sanctioning institution the resource is overused relative to the Nash equilibrium with homogeneous, self-interested agents ('classical' Nash equilibrium). People cooperate less than expected according to that model and are worse off than the model predicts.

(i) Actual resource use is greater than the classical Nash equilibrium.

(ii) The phenomenon is not explained by learning or experience.

< ***Table 3 about here*** >

Support:

(i) In terms of efficiency the groups scored 28.4% of the maximum possible net return, a value that is in-between the classical Nash equilibrium level of 39.5% and the open access level of 0%. The overall average of the group use for the four experiments was 131.3, which is statistically different from both the above reference values at a 0.01 level[16] (see Table 3 for details). The group use varied considerably across periods, ranging from a minimum of 85.5 to a maximum of 167 tokens.

(ii) Learning or experience effects do not alter the main conclusion that the group use is persistently above the one-shot classical Nash equilibrium level. There is no support in the data for the claim of temporary off-equilibrium outcomes due to learning or experience:

- Experienced subjects do not perform better than inexperienced subjects do. Differences in efficiencies actually favor inexperienced subjects (25.2% versus 31.6%, Figure 3).
- A comparison between the first half, second half, and after announcement period averages[17] show no statistical differences at 0.01 significance level. As an overall average, the values are 131.37 in the first half, 131.39 in the second half, and 130.31 after the announcement (Figure 4).

The volatility of the group use level decreases over time in three out of four experiments (see variance comparisons in Table 3) but it mostly reflects oscillations around the same average.

There is a much milder condition that ensures that at least 87.5%(i.e. 7/8) of the actions is inspected (It suffice that at least one agent is not strongly altruistic, $\gamma_{(1)} < 0.08$).

16 The symmetric Nash equilibrium value X=128 was never recorded in any of the 129 rounds in which the appropriation decisions were taken. The open access level is X=144.

17 In no sanction experiments, the first half includes periods 1-15, second half 16-30 (or 16-31), and after announcement 31-32 (or 32-33). In sanction treatment, the first half includes periods 1-12, second half 13-25 , and after announcement 26-27.

< ***Figure 3 about here*** >

We can further analyze the evolution of group use over time. Agents know they are involved in a repeated interaction and they are not told the number of rounds they will go through. The probability that an additional round will be run decreases over time. If in the initial round agents can support a better resource use than the one-shot Nash equilibrium, such level will move progressively closer to the latter as the experiment unfolds. If a repeated interaction effect is present, the pattern in the total group use should be

(a) A convergence to the one-shot Nash equilibrium from below, i.e. in the range $X \in [72, 128)$;

(b) An eventual jump to the one-shot Nash equilibrium level after the end-of-experiment announcement has been made.

The data show a weak support for (a) and no support for (b).

< ***Figure 4 about here*** >

The presence of a repeated interaction effect and of learning effects will be evaluated by the application on the data of the Ashenfelter-El Gamal model, which is described in Noussair et al (1995). The model assumes that total group use may start from a different origin for each experiment, but the convergence is assumed to be a common asymptote in all four experiments. Formally the model is as follows:

$$X_{mt} = B_{11} D_1 \frac{1}{t} + B_{12} D_2 \frac{1}{t} + B_{13} D_3 \frac{1}{t} + B_{14} D_4 \frac{1}{t} + B_2 \frac{t-1}{t} + u_{mt}$$

Where m is the index of the experiment; D_k are dummy variables that take value 1 if m=k and value 0 otherwise; t is time measured in terms of experimental period number; X_{mt} is the total group use in period t of experiment m. B_{1m} measures origin of the group use convergence process, and B_2 is an asymptote. Data in Table 3 show the estimation of the model.

The asymptote for the no sanction experiments is 134.0, which is statistically different from the equilibrium level of 128 but not significantly different from the overall average group use of 131.3 at a 0.05 level. This result confirms once more that the overuse of the resource persists and does not tend to die out. The convergence to the asymptote starts from below for all the experiments.

Result 1B. A model of heterogeneous, other regarding agents is compatible with the resource use data in a sanction-free environment better than the classical model both at the aggregate and the individual levels. Furthermore, some clues exist in the data suggesting that heterogeneity is an appropriate modification to the classical model. Specifically,

(i) Over use and under use are properties of individuals. About 37% of the agents are other-regarding and most of them are spiteful.

(ii) Self-reported other-regarding preferences are documented

Support: The observed level of group use can be explained by the heterogeneous, other-regarding agent model given an appropriate pattern of group preferences that is biased toward spite[18]. Individual actions are very dispersed relative to the classical individual Nash equilibrium x_i=16 (a) and this variability is due to individual heterogeneity (b). Individual heterogeneity is not a consequence of confusion (c) but is consistent over time (d) and is due to other-regarding preferences (e), (f).

(a) The patterns of individual use do not conform to the one-shot classical Nash equilibrium prediction. The actions within a 25% bandwidth around the prediction (i.e. in the interval [14, 18]) account for 15.7% of all the actions[19] and the rest are not symmetrically distributed around that value: about 61% are below and 23.3% are above. The mean is 16.42 and the standard deviation is 10.00.

(b) A brief look at the individual average use levels makes clear that agents are heterogeneous and that only a few agents were accountable for a systematic over-use (Figure 5). We can reject the hypothesis that the agent average use is at the individual symmetric Nash equilibrium (x_i=16) for 28 out of 32 agents at 0.05 level (see white bars in Figure 5). Within each experiment there are at least four different types of agents whom use behavior is statistically different at 0.05 level. The presence of different types of individuals is a common finding in the experimental literature (Von Winden, Dijk, Sonnemans, 1998)

(c) There are reasons to believe that the differences in individual behavior are traits of the agents and are not due to confusion. The experimental design was not simple and a possible explanation of such behavior is that the " heavy users" might have been confused subjects who

[18] Consider for example a group with three types of agents: two are moderately altruistic γ_i =1/21, four self-interested agents, and two quite spiteful ones γ_i =- ¼. The group appropriation is X*=132 with individual appropriations x_i of 6, 12, and 36 respectively.

[19] The actions exactly at x_i=16 are 26 (2.52%).

did not properly understand the incentive structure of the experiment[20]. The evidence from the quiz completed by each subject before the experiment does not show any support for this option. We have assigned a score to each quiz taken, which is 1 if all the answers are correct, 0.5 if some answers are not perfect but it is clear that the subject overall understood the rules, and 0 if there are substantial and repeated mistakes. The four highest users score an average of 0.92 against a general average of the 32 subjects of 0.89. In other words, the heavy users seems – if something - better skilled than average.

(d) There is a remarkable consistency over time in the individual use patterns, which indicates that the differences across agents are purposive rather than random. A rough measure of time consistency comes from the comparison of the agent average use levels of the first and second half of the experiment. The greater the similarity between the two values, the stronger the consistency claim can be. In order to compare the correlation of the individual use levels over time, we have run an ordinary least square regression on agent ranking. Each agent has been assigned her ranking position in terms of average use within the experimental group. The first-half-of-the-experiment ranking has been regressed on the second-half-of-the-experiment ranking without a constant term. Rank correlation informs on the existence of any form of monotonic relation between the values and it is a better choice than absolute value correlation, which can capture only linear relations between the two variables. When using ranks, the coefficient is in the interval [-1, +1]. A negative value denotes a decreasing relation and a positive value denotes an increasing relation. The higher the absolute value, the stronger the monotonic relation is. A zero value means that there is no monotonic relation at all. Our best result will be a 1-value coefficient. When all the no sanction experiments are pooled together, the estimated coefficient is 0.936 (number of observations is 32, R-squared 0.88. See Table 3 for single experiment regressions). This test supports the view that over time agents are consistently heterogeneous.

(e) From here to make precise statements on the nature of unobservable preferences there is a jump. We find some help in the use strategy notes that the participants left on their final questionnaire, which often mention other agents' earnings. Here is one: " My greed went to the extent of causing me not to want to fall behind having at least 1/8 of the market share because I

[20] If the heavy investors are confused subjects, however, it is unclear why we do not find them in the experiment with the weak sanction treatment (see Figure 5). Such experimental design is more complex than the no sanction design, although the threshold level for sanctioning gives a vague clue about the equilibrium level and the monetary incentive against high appropriation levels are higher.

didn't want others making more profit per period." One of the highest users explicitly mentioned in the description of his strategy the goal of decreasing the earnings of the others: " [I] tried to keep a large portion of the token used by forcing the others to adjust their use so that the total would be profitable".

(f) The estimation of the other-regarding agent model on the experimental data leads to consistent results. Since the difference between the classical and other-regarding model is just in the slope of the best response function (cfr. (2) and (2'')); see also Figure 2), the regressions assume a correct value for the intercept. The estimation is done under the assumption that the agents expect the others to act in period t as they did in period t-1: $x_{i,t} = 72 - \frac{(1+\gamma_i)}{2} x_{-i,t-1} + \varepsilon_i$. All the 32 agent-specific estimated values of the slope fall into the allowed interval [-1,0] corresponding to an other-regarding parameter $\gamma_i \in$[-1,+1]. The γ_i estimates range from a minimum of -0.40 to a maximum of 0.08. About 37% of the agents have a parameter γ_i significantly different from zero at a 0.05 level and our model classifies them as either altruistic when γ_i is positive (2 agents) or spiteful when γ_i is negative (10 agents).

< ***Figure 5 about here*** >

To sum up, group efficiency is below the classical Nash equilibrium level (at 39.5% efficiency) and precisely at 29.5% in our experiments. WGO reported an average negative efficiency (-3.2%) but at a closer analysis the difference between the two studies occurs in the earlier rounds and dies out over time: the convergence values estimated with the Ashenfelter-El Gamal model are statistically indistinguishable (131.97 WGO and 133.78 ours), although our data reject the Nash equilibrium value of X=128 at a 0.05 level where WGO data are more noisy[21]. Moreover, individual actions are widely heterogeneous. WGO's report that in the 48% of the rounds not a single agent used 16 tokens. In our experiments the figure is 90%[22]

[21] Average group efficiency is computed using WGO's 3 experiments and the first 20 rounds of the 4 no sanction experiment in this paper. The 0.95 confidence interval of the Ashenfelter-El Gamal asymptotes are[124.38, 139.56] for WGO and [129.33, 138.22] for ours.

[22] Part of the increase observed in our experiments might be due to the re-scaling of the action space and to the opportunity to invest any real and not only integer number.

The predominance of spiteful agents over altruistic ones can account both for the overuse at the group level and for the observed pattern of individual actions. A model relying on homogeneous, self-interested agents cannot explain either one of the two regularities[23].

8. RESULTS OF WEAK SANCTION EXPERIMENTS

This section describes the outcome of four experiments run under the weak sanction treatment and in particular it focuses on the inspection decisions (Result 3) and their effects on the use decisions (Result 2).

Result 2. With the introduction of weak sanctions,

(i) Group efficiency improves substantially. Resource use efficiency moves from below the classical Nash Equilibrium to above the classical Nash equilibrium.

(ii) Inequality in the individual use of the resource decreases relative to the no sanction design

These results are not predicted by the classical model (Proposition 2A) but they are consistent with the heterogeneous, other regarding agent model (Proposition 2B).

Support:

(i) The efficiency level is considerably higher with weak sanctions than without sanctions and is well above the classical Nash equilibrium prediction (39.5%) for any specific index considered. The gross efficiency level has roughly doubled (28.4% without sanctions, 57.19% with weak sanctions). The change is minimal when we correct for the differences in length among experiments and consider the first 25 periods only (28.9% versus 56.21%).

Requesting sanctions is a costly activity and so a fair comparison needs to consider the cost of the inspection mechanism. In fact, inspection fees are a deadweight loss for the group and as such needs to be subtracted from the rent extracted under the sanction treatments. The amount

23 The experimental data might be explained by different specifications of other-regarding preference models. One option is a reciprocity model (Falk, Fehr, and Fischbacher, 2000). Another alternative specification is the *status seeker* model: $U_i(\pi_i, \Pi_{-i}) = \pi_i + \delta_i (\pi_i / \Pi_{-i})$, where $\delta_i>0$ when agents care about relative income and $\delta_i = 0$ for pure self-interested agents (see Ito, Saijo, and Une, 1995). This latter model has been set aside for several reasons. The status seeker model does not have any room for "altruistic" actions; it has a very unnatural behavior for group appropriation levels above the open access level (X>144) because both π_i , $\Pi_{-i} <0$. Regarding inspection decision, the status seeker model predicts that agents never request inspections for $(\pi_i / \Pi_{-i})<1/\theta$, which implies that nobody inspects if they expect a loss. Moreover, poor agents request fewer inspections than rich ones (there is however a need to define wealth as current or cumulative earnings).

of the fines is, instead, a plain transfer from an agent to another and is not a cost from the group standpoint. When the inspection fees (8.9%) are subtracted, the net rent is 48.3%, which is about twenty points above the no sanction level (cfr. Tables 3 and 5). When the agents are experienced the efficiency improvement is even greater: the net rent of experienced subjects is on average 62.02% versus a 34.56% of inexperienced ones (see Figure 3).

The total group use is substantially lower for sanction experiments than for no sanction ones. As an overall average, group use drops from 131.3 to 115.5 tokens (statistically different at 0.01 level). The aggregate use is statistically different from both the classical Nash equilibrium and the socially optimal level (0.01 level). The classical Nash equilibrium X=128 was recorded in the 1.85% of the rounds (2 out of 108). When considering the classical model, the overall group use average is not statistically different from the one-probability inspection prediction (X=113.7) but it is for one experimental session run with experienced subjects (0.05 level). The group use across periods ranged from a minimum of 87 to a maximum of 186.8, which is wider than the same range for no sanction experiments.

Similar results come from the estimation of the Ashenfelter-El Gamal model explained in Section 7. The ordinary least squared asymptote of X=114.8 is not significantly different from the one-probability inspection level (0.05 level) while it is from the zero-probability level (see Table 3).

(ii) Agent inequality decreases compare to the no sanction treatment. The spread in average use levels between the highest and the lowest users greatly decreased with the introduction of weak sanctions and inequalities in use levels measured using Gini coefficients fell dramatically (Table 3). As a direct consequence, income inequalities from use decreased[24].

The comparison of the results in the no-sanction and sanction environments is carried on under the assumption that agents were drawn from a population with identical preference patterns. Even if the agents were not the same in the different experiments, we think that the conclusions drawn under the above assumption are reasonable.

Result 3. With the introduction of weak sanctions, about half of the actions are inspected.

[24] Income from appropriation is defined as the gross revenues from appropriation minus the cost of tokens and it excludes the period endowment as well as costs and revenues from the inspection activity. There is a very strong linear correlation between average appropriation levels and average income from appropriation (0.97 for all experiments, 0.99 for no sanction experiments) and this fact explains the tight link between the Gini coefficients for the two variables. The standard deviation of average appropriation and income levels exhibit similar patterns.

(i) The number of inspections exceeds the number that is profitable. In fact twice the number of inspections take place than is ex-post profitable.

(ii) The highest users are more aggressive inspectors than the lowest users

These results are not predicted by the classical model (Proposition 3A) but they are consistent with the heterogeneous, other regarding agent model (Proposition 3B). Some inspection decisions can be classified as mistakes.

Support:

(i) The prediction of the classical model of no inspections is clearly incorrect, since 51.5% of the actions were inspected (Table 4) when only 18.4% were profitable to inspect. Some of the inspections turn out in a positive income for the inspector while others in a loss (when $x_i<16$). The inspections with a negative balance were either mistakes due to the asymmetric information or purposive decisions of other-regarding agents. We will investigate both possibilities.

< ***Table 4 about here*** >

For a given group use level, the agents know the number of over-users if they know the empirical density function of the agent types. In the first period, however, they don't know the identity of such agents.

The number of actual inspections compared to the number of potentially profitable ones is very high (about twice as many). This ratio does not decline as the agents get more familiar with the inspection device (1.86 inexperience versus 2.22 experienced subjects) and as the agents reveal their type during the experiment (2.02 first half of the experiment, 2.13 second half, 1.82 after announcement)[25].

< ***Table 5 about here*** >

We know that spiteful agents will purposely request some un-profitable inspections. If fact, when an inspection was requested, it was unprofitable about 62% of the times (Table 4). While

25 About 35.1% of the inspecting decisions generated a lower income for the inspector that they could have, either because a potentially profitable inspection has not been requested (type I error) or because a potentially non-profitable inspection has been requested (type II error). Such "error rate" is substantially lower for experienced agents (29.2% versus 41.0%). In spite of the excessive inspecting activity, the inspection balance is close to the zero level ([-1.5%, +1%] in terms of the maximum rent). Type II errors are higher than type I errors (42.6% versus 17.0%). See Table 5.

the heterogeneous, other-regarding agent model is compatible with such behavior as long as the reward parameter is $\vartheta<1$, there are decisions that only extremely spiteful agents would willingfully request. Since section 6 defined as acceptable range for other-regarding attitudes the interval $\gamma_i \in [-1, +1]$, decision to inspect other agents where $\vartheta>1$ are classified as mistakes.[26]. According to such definition, in the weak sanction environment 18.7% of the inspecting actions are considered mistakes. In other words, the high number of unprofitable inspections is due to agent mistakes as much as it is due to spiteful preferences.

(ii) As predicted by the heterogeneous, other-regarding agent model (proposition 3B), spiteful agents are more aggressive inspectors than altruistic agents.

Agents were divided into three groups according to their average use level in the experiment. The inspecting behaviors of high versus low users was compared keeping out of the analyses the group of median users among whom there were no significant differences in individual use at a 0.05 level. Relatively spiteful agents requested on average more inspections per period than relatively altruistic agents did, when controlling for the resource use by all the other agents in the group. This conclusion is based on the sign and significance of the coefficient of the dummy variable for highest users in Table 6 (positive for weak sanctions, negative for strong sanctions)[27].

< ***Table 6 about here*** >

Although preferences do not account for all the inspection "errors", they play a relevant role. More investigations are needed on the beliefs about other agents' use levels (see for instance Coats and Neilson, 1999).

9. RESULTS OF STRONG SANCTION EXPERIMENTS

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[26] In our sanction design the reward parameter ϑ increases with the individual appropriation level of the targeted agent in the interval $x_j \in (\lambda, \underline{x})$, where $\underline{x} = \lambda + (k/h)$. In particular, $\vartheta = [h_j (x_j - \lambda)]/[k - h_j (x_j - \lambda)]$ if $\lambda < x_j < \underline{x}$. Some numerical values: for weak sanctions, $\vartheta=1$ when $x_j=12.5$, $\vartheta=2$ when $x_j=13.66$ and $\vartheta=4$ when $x_j=14.75$; for strong sanctions, $\vartheta=1$ when $x_j=7.87$, $\vartheta=2$ when $x_j=8.16$ and $\vartheta=4$ when $x_j=8.4$. In the interval $[0, \lambda)$ no sanction is allowed and in $(\underline{x}, \hat{x}]$ inspecting is actually profitable and not costly, so ϑ is ill-defined.

[27] Regressions for each single experiment confirm this general conclusion with the exception of one of the weak sanction experiment (0225) where the highest investors dummy is not significant at 0.10 level.

Result 4. Strong sanctions have the effect of increasing resource use efficiency as predicted by both the classical and the heterogeneous, other-regarding agent models.

Efficiency levels fall short of the Nash equilibrium of both models. Experienced subjects tend to be closer to the equilibrium.

Support: In the two strong sanction experiments, the total group use was on average 85.1. This level was significantly (0.01 level) higher than the outcome predicted by both the standard model (71.1) and the heterogeneous, other-regarding agent model ([64, 72]). The conclusion does not change when the Ashenfelter-El Gamal model is estimated. The ordinary least squared asymptote is 86.13 (Table 3) and none of the predicted values are in its 95% confidence interval. The group use across periods ranged from a minimum of 69 to a maximum of 126.

The efficiency level is very high, 93.98%, but still sub-optimal and lower than the target level. When the inspection fees (17.12%) are subtracted, the net rent is 76.87% (Tables 3 and 5). Sub-optimality might be due to the inexperience of subjects, since there is a significant improvement in the group efficiency when subjects are experienced (gross rent 98.24% versus 89.73%)[28].

Result 5. In the strong sanction environment the heterogeneous, other-regarding agent model performs better in predicting inspections than the classical model. In particular,

(i) The number of inspections exceeds the number that is profitable. In fact about 50% more inspections take place than is ex-post profitable.

(ii) The lowest users are more aggressive inspectors than the highest users

These results are not predicted by the classical model (Proposition 5A) but they are consistent with the heterogeneous, other regarding agent model (Proposition 5B). Some inspection decisions can be classified as mistakes.

Support:

(i) About 99.1% of the actions were inspected, a value definitely close to the 100% predicted[29]. The ratio between the undergone inspections over potentially non-negative balance inspections is

[28] The inequality in the average use across agents is substantially lower than in the no sanction environment (Table 3). The average standard deviation of the agent period earnings from appropriation is of 5.6 francs and 1.6 francs ones fines are subtracted.

[29] Although almost all the agents were inspected every period, not all the agents requested to inspect everybody every period, as predicted by the classical model. On average an agent requested less than 4 inspections per period instead of 7.

1.49, which is high but less severe than in the weak sanction experiments[30]. All potentially profitable inspections were requested. Unprofitable inspections that were requested and turned out to have a reward parameter $\vartheta>1$ – decisions classified as mistakes - amounted to 25% of all the inspecting actions. About three quarters of the unprofitable inspection decisions are attributed to mistakes rather than to spiteful behavior (Table 4).

(ii) Relatively spiteful agents (lower users) are more aggressive inspectors than relatively altruistic agents (higher users) since the coefficient of the *highest user* variable is negative correlated and significantly so with the number of inspections (Table 6).

The functioning of the inspection mechanism under the strong sanction treatment reveals similar features than under the weak sanction treatment. There are too many inspections and the relatively spiteful agents (lower users) are more active inspectors than relatively altruistic agents (higher users) are.

10. CONCLUSIONS

The study supports four major conclusions. First, the sanctioning institution, the *Carte di Regola*, had a dramatic effect on pressuring the common pool resource to efficient use levels, given that such levels are known and need only be enforced. Secondly, a modification of the classical model to include heterogeneous, other-regarding preferences seems to account for much of what is observed. Third, the major results of the Walker, Gardner and Ostrom, 1990 (WGO) paper are replicated. Thus, the patterns of data that were interpreted as the spite/altruistic paradox - which motivated a close examination of their work - are also found in our data. The fourth conclusion is that the same model of heterogeneous preferences that accounts for our data also accounts for their data in addition to the data from some other, closely related studies.

The heterogeneous, other regarding agent model provides room for altruistic, self-interested, and spiteful agents who care to different degrees about other people's earnings. For example, spiteful agents, who find enjoyment in decreasing the earnings of others, play an important role.

[30] The surprise is the inspection balance that is largely positive. In equilibrium with (X*,p*) = (71.1, 1), we expect an inspection balance about 1.4% of the maximum rent. Data talk of an average balance of 18.8%, more than ten times higher than what was predicted. The reason of such "success" was not mainly in the exceptional ability in discovering high investors but in the high average value of total group appropriation. In fact, about 32.6% of the inspecting decisions were incorrect, which is only slightly lower than in weak sanction. The type II error is very high (0.972) and there are no type I errors.

While the model seems to resolve the spite/altruistic paradox, it does much more in providing insights about why the sanctioning institutions represented by the *Carte di Regola* are so powerful and might have lasted so many centuries in rural villages. The institution channels two possibly harmful human tendencies, irrationality (a tendency to make mistakes) and spitefulness, into the creation of a useful social incentive system.

A summary of results that lead to these conclusions is easiest to explain with a focus, first, on the two major results of Walker, Gardner, and Ostrom, 1990 (WGO). Both are related to common-pool resource use in a sanction-free environment and both were replicated. First, they find that individual actions are heterogeneous. At the individual level, the one-shot Nash equilibrium prediction of identical actions across agents is definitely rejected in favor of a model of heterogeneous agents. They produced the result and we replicated it (Result 1B). Secondly, the tragedy of the commons is more severe than would be expected from an examination of levels of cooperation in public goods environments. The levels are even higher (efficiency lower) than self interested free riders would choose. WGO produced the result and we replicated it. However, we go further and demonstrate that the result is explained when other regardingness is added to the model (Result 1 A). In this sense, the "spite/altruistic paradox" is clearly evident in our data as well as in theirs and the paradox is resolved by the model.

Having reflected on the heterogeneous, other regarding agents model, its consistency with additional data found in the literature is apparent. Given its flexibility beyond that of the classical Nash model, the heterogeneous, other regarding model provides insights about three rather perplexing aspects of behavior uncovered by other experiments, beyond the spiteful/altruist paradox.

First it is not clear why the sanctioning system used in the WGO study should work. Within the classical model there is no incentive for anyone to administer sanctions in the context of the institutions studied by WGO. Individuals, who choose to punish others when there is a cost to administering punishment and no reward, are not behaving according to the classical Nash equilibrium model. In the generalization of the classical model the motivation is easy to find and the perplexing behavior can be understood. It is because spite plays a role. The spiteful agent gets utility from imposing sanctions on others.

Secondly, the WGO experiments contain another aspect of behavior that is not so easy to explain for both the classical model and the heterogeneous, other regarding agent model. The issue is the choice of whom a spiteful person will inspect or punish. Within the *Carte di Regola* institution the prediction of who to inspect is clear because the agent who successfully identifies a violator is rewarded with the amount of the sanction and the sanction level varies with the use level. Thus, one always inspects suspected violators. However, within the sanction institutions studied by WGO that is not the case. Without a differential reward – as it is the case of WGO - the spiteful person of the model does not care who is punished so long as someone is. But, subjects in the WGO experiments target their punishments to the particular individuals who are large users of the resource. In order to explain such phenomena the heterogeneous, other regarding model must be amended. Two candidates for change represent themselves. One is the introduction of attitudes of reciprocity (Fehr and Gatcher, 1999; Falk, Fehr, and Fischbacher, 2000). The second is to include the possibility of repeated play. Which of these explanations might be more reliable cannot be answered in the context of our experimental design. Thus, for now, the heterogeneous, other regarding model remains incomplete.

The third perplexing phenomena found in the WGO study is found as a result of their change of the maximum level of individual resource use allowed. Basically, in one treatment the individual "strategy space" was expanded without any other change in the rest of the experimental design. Suppose the admissible levels of use are increased in a manner that preserves the initial Nash equilibrium. In essence, this increase in the upper bound simply supplies agents with options that are irrelevant to their actions from the point of view of classical model. The surprising effect, observed and reported by WGO, is that such a change in the design is accompanied by an increase in the levels of use. That is, options that should have no impact at all have a systematic impact.

A generalization of the classical model to include the possibility of heterogeneous, other regarding individuals, provides a potential explanation for this third, perplexing aspect. Proposition 1B demonstrates that the addition of spiteful agents is in fact accompanied by an increase in use levels.   While individual data are not available from the WGO study, such data that are available suggest that some individual choices of use in the WGO experiments were at the maximum possible[31]. A natural interpretation is that they had spiteful agents in their experiments that were exploiting the resource to the maximum of their ability. An increase in the amount they could use would remove a constraint on their behavior and result in still greater levels of use.

The primary purpose of the research reported here is to study the effectiveness of an ancient method of managing renewable resources. The first conclusion is related to the impact of the special

[31] In the experiments with a "restricted strategy space", the modal strategic response of individuals was to use the resource to the maximum of their ability (Ostrom, Gardner, and Walker, 1993, p.121).

monitoring and sanctioning institution. The rules of the institution were fashioned after the historical case of use of a common pool resource in the Italian Alps called *Carte di Regola*, where people could inspect one another and inflict punishments according to some rules that could be enforced in a court of law. While the differences between this institution and others might seem subtle, the impact is pronounced.

The overriding result is that the *Carte di Regola* greatly improves the efficiency of the resource use. It is important to note that the improvement is not only in terms of gross efficiency but also net efficiency, where the costs of administering the system (the inspection fees) are deducted. Under the weak sanction treatment there is a spectacular improvement in gross efficiency (from 28.4% to 57.2%) that is not predicted by the classical model. Once the inspecting costs are considered, (net) efficiency remains very high (48.3%). Group behavior in the strong sanction environment shows large improvements (from 28.4% to 94% gross, or 76.9% net) but is not at the optimal level, as was instead predicted by both classical and heterogeneous, other-regarding agent models (Results 2 and 4).

The second overriding result is related to the relative accuracy of the model we apply. The prediction of the heterogeneous, other-regarding agent model is that spiteful agents are more aggressive inspectors than altruistic agents under all conditions (weak and strong sanctions). In fact, the spiteful agents are even willing to request unprofitable inspections. On the other hand the level of use of the resource by the spiteful agents relative to altruistic agents reverses from relative heavy user to least user as the treatment is changed from weak to strong sanctions. This seemingly perverse relationship, the flip in the relative behavior, is exactly reflected in the data from the experiments (Results 3 and 5). On the other hand, the high rate of unprofitable inspections is understandable in part as spiteful behavior and in part as mistakes originating from wrong beliefs about the individual use levels of the other agents (Result 3 and 5).

In the explanation of the results under all experimental treatments a key role is played by the heterogeneity of behavior of the agents, and in particular by the presence of few spiteful agents. Thus, the major theoretical advance resulting from the experiments is that two major elements of the model, other regarding preferences and heterogeneity of agents, are important keys to the understanding of behavior concerning common pool resources and institutions designed and implemented to protect them. The self-administered monitoring and sanctioning system studied in this paper performed very well in helping solve the "tragedy of the commons". In our view, its main strength is the ability of such institution to turn individual mistakes and socially harmful attitudes into beneficial actions for the group through the possibility of inspections that modify agent incentives. In fact, individuals who mistakenly inspect others are providing a public good by bearing the monitoring cost of the system. The *Carte di Regola* system has channeled spite into better group performances. This feature might have been one reason for its endurance. Maintaining an inspection mechanism involves a deadweight loss for the group but a careful choice of the parameters could bring benefits that compensate many times for that loss.

By focusing on the *Carte di Regola* one can identify a broad fabric of institutions, together with how other studies fit in that fabric, and speculate about the role of subtle institutional differences in shaping overall social behavior. Table 1 produces a list of institutional features each of which can be interpreted as a module to be added or removed in the creation of special sanctioning systems. How these modules may interact or whether interesting systems can be developed from them remains to be explored. Clearly the *Carte di Regola* does not solve all of the public goods problems and in particular does not address the most obvious problem of determining how much of the public good should exist (or similarly, how much the resource should be used). However, the system does provide parameters that can be adjusted to control uses of environmental resources. Because the parameters are rule based, the *Carte di Regola* can be differentiated from social sanction systems, such as a system of vigilantes, in which the level of sanction and even whether or not a sanction should be imposed is the decision of self appointed inspectors within the system. This capacity for parameter adjustment through rule changes, and the sequential trail and error decisions it facilitates, might provide a step in solving the difficult problem of determining optimum levels.

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APPENDIX A: PARAMETERS OF THE NO SANCTION DESIGN

Our design:

Number of people in the group: 8 Conversion rate $ 0.04 per 1 franc

Total group earnings (in francs): $\pi_i = 2.5 \cdot (E - x_i) + \frac{x_i}{X} \cdot f(X)$

where $x_i \in [0, \hat{x}]$ *for* $i=1, .. ,8$; $\hat{x}=50$; the cost of tokens is $2.5 \cdot (E - x_i)$; endowment E=4 or E=0, and

Gross group return
$$f(X) = \begin{cases} \frac{23}{2} X - \frac{1}{16} X^2, if\ X \le 184 \\ 200 \cdot [e^{-0.0575(X-184)} - 1], if\ X > 184 \end{cases}$$

Walker, Gardner, and Ostrom (1990) high endowment design (WGO):

Number of people in the group: 8 Conversion rate $ 0.01 per 1 franc

Total group earnings (in francs): $\pi_i = 5 \cdot (25 - x_i) + \frac{x_i}{X} \cdot f(X)$

where $x_i \in [0, 25]$ *for* $i=1, .. ,8$; market 1 earnings are $5 \cdot (E - x_i)$; the endowment is E=25, and

Market 2 earnings $f(X) = 23 \cdot X - \frac{1}{4} X^2$

There are differences between our no sanction design and WGO both in the incentive structure (1-4) and in the way the information is conveyed (A-D) (earnings are expressed in dollars per person per period):

1. The **range of the choice variable x_i has been rescaled** from [0,25] to [0,50] because the difference between two possible equilibrium points, Nash equilibrium and open access, was just one unit. Increasing the perceived number of steps from 25 to 50 might lead to a more accurate use decision. Moreover, in pilot experiments we noticed that people generally input integer numbers even if the software allowed any real number. This fact may be a problem since in WGO the socially optimal use level corresponds to a non-integer individual use (4.5 tokens).
2. The **conversion rate franc/dollar has been increased four times** from $ 0.01 to $ 0.04 per 1 franc in order to maintain a higher effort level by the participants in the experiment. As a result, the *difference* in terms of *individual* earnings between the social optimum and open access points has increased from $ 0.405 to $ 1.62. The adjustment has been suggested by the playful behavior of some subjects during the pilot experiment when the low conversion rate was used.
3. The **minimum safe earning level has been decreased**. If nothing is used in the "risky" market 2, the original earnings were $1.25. In our setting a zero use (x_i=0) yields a period return of $0.4 (when E=4). The change implies a downward shift in the payoff but does not affect the incentive structure. The reason of the change is to limit the maximum earnings that would have otherwise been too high given the new conversion rate (point 2).
4. The **Gross group return has been modified** in the interval [184, 400]. The function *f(X)* now has a lower bound at –200 francs that is much higher than it originally was. A group use of X=184 has an efficiency of –142% in both settings. At X=400 the difference in dollar earnings is small ($ –5.6 instead of $ –6.75). The reason for the change is to limit the maximum loss given the new conversion rate in case people "go crazy" (see point 2). In the experiments conducted, we observed an use level above 184 just in one round out of 291.

< ***Table 1A about here*** >

A. **Graph instead of formula**. WGO provided the subjects with the analytical expression of the gross group return from market 2. The expression may have been used to compute the equilibrium. We replaced it with a plot of the function f(X) because we think that the graph would easy the understanding of the basic underlying phenomenon. The graph in the instructions is similar to the upper part of Figure 1 once the cost line is removed.
B. **Detailed table.** In order to compute the equilibrium, subjects could use a very detailed table of gross group return. The table gives the gross group return and the return per token used for 100 values of the total group use, compared to the 10 values given by WGO. All theoretical equilibrium points are listed in the table given to the subjects. Our table does not supply the marginal returns, which instead WGO provided.
C. **Different software**. The software was run on Netscape and was written specifically for this application. It includes a calculator to compute the cost of tokens, the gross group return, and the individual share of gross for every possible real level of use in the admissible range.
D. In WGO **market 1** represents the *opportunity cost* of the use and yields a constant return. The way in which it was presented to the subjects in this study is as a *direct cost* of the use. You can order the tokens to use and pay a constant unit price for them. This change may make the decision of the agents easier by suggesting a comparison of the price of tokens with the return from the market.

< ***Table 3A about here*** >

APPENDIX B: INSTRUCTIONS

Important note: The instructions reported below are for weak sanction experiments with E=4 (0225, 0824, 0408). The instructions for sanction-free experiments with E=4 (0216, 0908, 0407) did not include the parts in square brackets.

This is an experiment in decision making. If you follow the instructions carefully and make good decisions you may earn a considerable amount of money. You will be paid in cash in private at the end of the experiment.

You will make most of your money by [either (1)] placing an order for tokens and INVESTING them in a market that will give you a cash return for your tokens [(See example #1 below), or (2) MONITORING other people's decisions and eventually getting some revenues from the inspections (See example #2 below)].

The experiment in which you are participating is comprised of a sequence of periods. In each period you will be asked to make an investment [and a monitoring] decision.

INVESTING

Each period you can place an order for a ***number of tokens between 0 and 50*** which will be automatically invested in the market. There are also ***seven*** other persons in this experiment who are making investment decisions on the same market. Everybody can place orders up to 50 tokens and so the total group investment is at most 400 (= 50 times 8 people).

For every token you order, you will be ***charged 2.5 francs*** and you will be credited a cash return from the market.

The return from the market is a bit complicated to explain. The return depends on the number of tokens you invest as well as the amount all others in the group invest. The total group investment determines the gross group return

(See table on the board) and you will receive a fraction of it according to your personal investment level. The example below explains the computation in detail.

You make your decision before knowing other people's investment decisions on that period. You are not to reveal your investment decision to anyone.

EXAMPLE [#1]

Suppose you place an order of 6 tokens to be invested in the market and everybody else does exactly the same.
The cost of your tokens is 15 francs, that is 6 tokens times 2.5 francs.
To compute your earnings in the market,

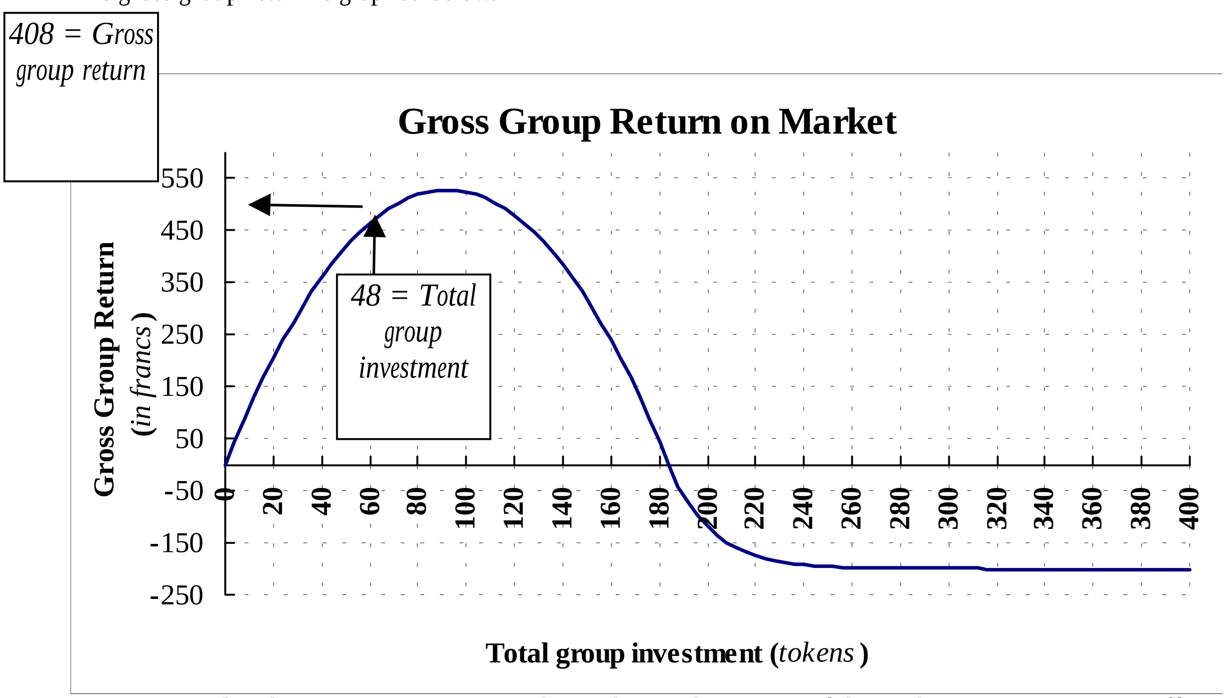
(1) first, compute the total group investment. In this example, the total group investment is 48 tokens (6 tokens times 8 people). The corresponding ***gross group return*** is 408 francs, as shown in the table on the board. The first column of the table lists the total group investment and the third column gives you the corresponding gross group return.

(2) The second step is to compute ***your share of gross***. You will receive a ***fraction of the gross group return that is equal to your fraction of total group investment***. You have invested $\frac{6}{48} = 0.125$ of total group investment and you will receive 0.125 of the gross group return: 51 francs is your share of gross (408*0.125).

Your net return is 36 francs (your share of gross, 51, minus the cost of the tokens, 15).

As a ***computational shortcut*** for your share of gross, you can multiply your personal investment level by the "Return per token invested" column of the table on the board,
that is 6 * 8.5 = 51. ■

The gross group return is graphed below.



Notice that the gross group return on the market can be negative if the total group investment is sufficiently large. For instance, if each person invests 42 tokens, the total group investment is 336 tokens and the gross group return is –200 francs. When considering the cost of the tokens, each person has to ***pay*** 130 francs.

To sum up, your ***period earnings*** [***from investment***] in francs are given by:

+ Your share of gross	51 +	←	See example [#1]
– Cost of tokens	15 –		
= *Your net return*	*36*		
+ Period endowment	10+	←	Fix amount
= *Period earnings*	*46*		

The period endowment is a constant amount and does not depend on the investment decisions.
In the example the period earnings in dollars are ______ (1 franc = ____ cents).

If you have any questions concerning the instructions feel free to raise your hand and an instructor will assist you.

[***MONITORING***

After the total group investment is revealed, you will have the chance to ***impose a payment to the people that invested more than 9 tokens in the market***. This payment will be given to you. Notice that if the total group investment is more than 72 tokens (that is 9 tokens times 8 people), at least one person invested more then 9 tokens.

You don't know the individual investments of the other people, but you can ask to uncover them by ***paying 7 francs for every person you ask to inspect*** (inspection fee). If the person inspected invested more than 9 tokens, she pays ***1 franc for every extra token***. You get this money (inspection revenue) and ***everybody will know the investment level of the person inspected***.

You make the monitoring decision when you know the total group investment, but before knowing other people's monitoring decisions.

An identification number will be assigned to every person to maintain anonymity and it must be considered strictly confidential.

EXAMPLE #2

Suppose the total group investment is 172 tokens and your investment is 24 tokens (you are ID #1). Before the monitoring, you know that 100 extra tokens were invested (=172 - 72) but you don't know who invested them. Well, you did part of the job with 15 tokens (=24 - 9), but there are other seven people around that invested 85 extra tokens. Suppose you ask to inspect person #2 and she has invested 34 tokens. You pay an inspection fee of 7 francs and get an inspection revenue of 25 francs (= (34 - 9) * 1). After your inspection, everybody will know that person #2 has invested 34 tokens, but ***your identity will not be revealed***.

Besides the period earnings from investment already explained above, your earnings will be affected by your and other people's monitoring decisions as follows:

	ID#1	ID#2		
Inspection Fee	- 7			
Inspection Revenue	+ 25		←	See example #2
Payment	____	- 25		
= *Balance*	+18	- 25		

■

If two or more people ask to inspect the same person, only one inspection will be executed. A person will be ***randomly selected*** and she will pay the inspection fee and get the eventual inspection revenue. The other inspectors will be treated as if they did not ask to inspect that person.
If you have any questions concerning the instructions feel free to raise your hand and somebody will assist you.]

Please, go through the review session in the next page and fill in the blank lines with the values you think are correct.

PRACTICE ID ______

REVIEW

Consider the following investment decisions:

ID#	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*Total group investment*
tokens	11	11	11	11	11	11	11	27	104

Suppose you are person #1. To compute your net return on the market let use the computational shortcut mentioned in the example [#1]. Take your investment of 11 tokens and multiply it by 5.00 (Return per token invested, second column of the table on the board) = 55 francs is your share of gross. Your net return is 27.5 francs (your share of gross = 55 minus the cost of tokens = 27.5).
Now, you go on.

Gross group return ______________
Person #2: Share of gross _________________ Net return ___________________
Person #8: Share of gross _________________ Net return ___________________
[Suppose you inspect person #2 and #8. Your inspection revenues will be:
Inspection Revenue from person #2 ____________ Balance (Insp. Revenue - Insp.Fee) ______
Inspection Revenue from person #8 ____________ Balance (Insp. Revenue - Insp.Fee) ______]

Now, suppose you decide to increase your personal investment to 43 tokens, while everybody else stays the same, hence the total group investment raises to 136 tokens.

Gross group return ______________
Person #1: Share of gross _________________ Net return ___________________
Person #2: Share of gross _________________ Net return ___________________
Person #8: Share of gross _________________ Net return ___________________
[Suppose this time somebody asks to inspect you (you will pay for every token above 9):
Person #1: Payment ________________]

■

Please, raise your hand if you have any questions and an instructor will assist you.
[Otherwise, please go on to the next page.]

PRELIMINARIES

1. At the beginning we will run a two-period experiment to get familiar with the rules. It will NOT affect your earnings.

2. During the real session***, an announcement will be made two periods before the end of the experiment.*** The total number of periods is unknown to you.

3. Please, sign and date the following financial agreement.
Should my total earnings from the experiment be negative, I agree to work in the Experimental Economics and Political Science Laboratory at a rate of 7 dollars per hour until the loss is repaid.
Name and Signature ____
Date ______________

(Please detach this sheet and give it to the experimenter)

GROSS GROUP RETURN on the market

1. Find out the actual group investment

2. Look at the average return of each token

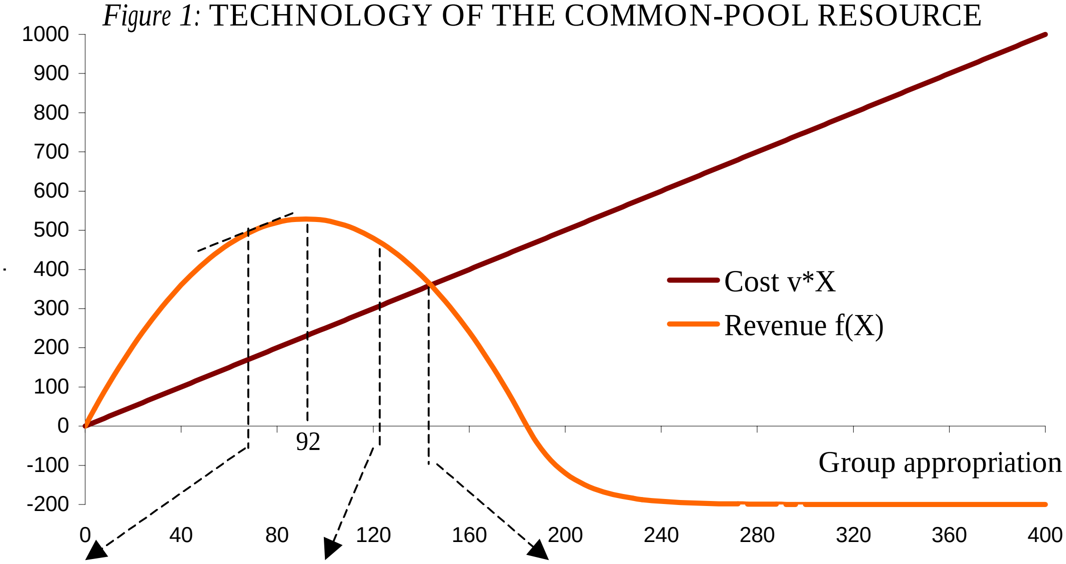
3. Multiply the average return by the number of tokens *you* have invested

Total group investment	*Return per token invested*	*Gross Group Return*
0	0.00	0.0
4	11.25	45.0
8	11.00	88.0
12	10.75	129.0
16	10.50	168.0
20	10.25	205.0
24	10.00	240.0
28	9.75	273.0
32	9.50	304.0
36	9.25	333.0
40	9.00	360.0
44	8.75	385.0
48	8.50	408.0
52	8.25	429.0
56	8.00	448.0
60	7.75	465.0
64	7.50	480.0
68	7.25	493.0
72	7.00	504.0
76	6.75	513.0
80	6.50	520.0
84	6.25	525.0
88	6.00	528.0
92	5.75	529.0
96	5.50	528.0
100	5.25	525.0
104	5.00	520.0
108	4.75	513.0
112	4.50	504.0
116	4.25	493.0
120	4.00	480.0
124	3.75	465.0
128	3.50	448.0
132	3.25	429.0
136	3.00	408.0
140	2.75	385.0
144	2.50	360.0
148	2.25	333.0
152	2.00	304.0
156	1.75	273.0
160	1.50	240.0
164	1.25	205.0
168	1.00	168.0
172	0.75	129.0
176	0.50	88.0
180	0.25	45.0
184	0.00	0.0
188	-0.22	-41.1
192	-0.38	-73.7
196	-0.51	-199.7
200	-0.60	-120.3
204	-0.67	-136.7
208	-0.72	-149.7
212	-0.75	-160.0
216	-0.78	-168.2
220	-0.79	-174.8
224	-0.80	-179.9
228	-0.81	-184.1
232	-0.81	-187.3
236	-0.80	-189.9
240	-0.80	-192.0
244	-0.79	-193.7
248	-0.79	-195.0
252	-0.78	-196.0
256	-0.77	-196.8
260	-0.76	-197.5
264	-0.75	-198.0
268	-0.74	-198.4
272	-0.73	-198.7
276	-0.72	-199.0
280	-0.71	-199.2
284	-0.70	-199.4
288	-0.69	-199.5
292	-0.68	-199.6
296	-0.67	-199.7
300	-0.67	-199.7
304	-0.66	-199.8
308	-0.65	-199.8
312	-0.64	-199.9
316	-0.63	-199.9
320	-0.62	-199.9
324	-0.62	-199.9
328	-0.61	-199.9
332	-0.60	-200.0
336	-0.60	-200.0
340	-0.59	-200.0
344	-0.58	-200.0
348	-0.57	-200.0
352	-0.57	-200.0
356	-0.56	-200.0
360	-0.56	-200.0
364	-0.55	-200.0
368	-0.54	-200.0
372	-0.54	-200.0
376	-0.53	-200.0
380	-0.53	-200.0
384	-0.52	-200.0

388	-0.52	-200.0
392	-0.51	-200.0
396	-0.51	-200.0
400	-0.50	-200.0

FIGURES and TABLES:

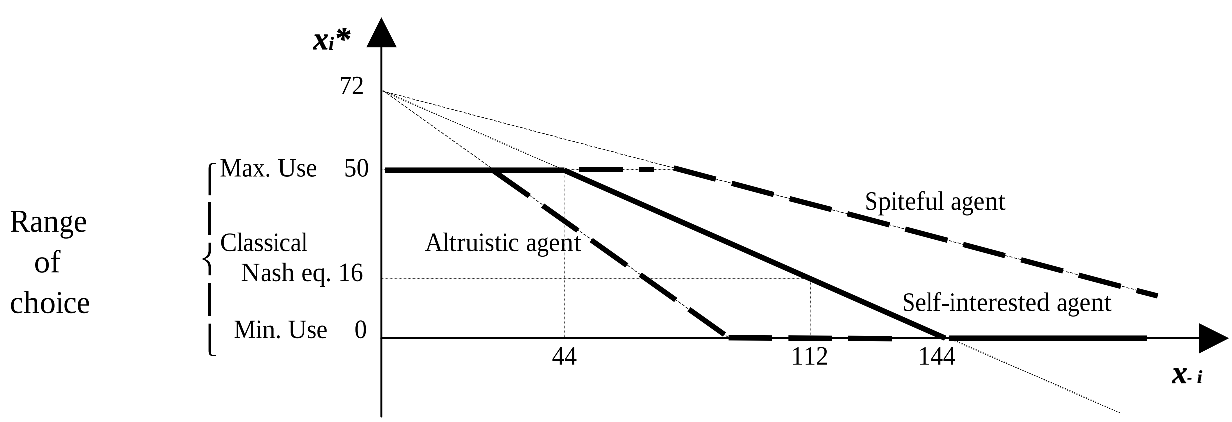
Figure 1: TECHNOLOGY OF THE COMMON-POOL RESOURCE



OPTIMAL USE	*NASH EQUILIBRIUM*	OPEN ACCESS	
72	128	144	Group use X
9	16	18	Symmetric individual use
100%	39.5%	0%	Efficiency level *(% of maximum rent)*

Notes: *The group welfare is $\Pi = f(X) - v{\cdot}X$, (the endowment E is set to zero); efficiency increases in [0,72) and decreases in (72,400]*

Figure 2: BEST RESPONSE FUNCTIONS, no-sanction treatment



Notes: In the no-sanction design (N=8, a=23/2, v=2.5, b=1/16) the classical best response function (selfish agent) is x_i= 72 - ½ x_{-I} (solid bold line)*

Figure 3: AVERAGE EFFICIENCY BY EXPERIMENT

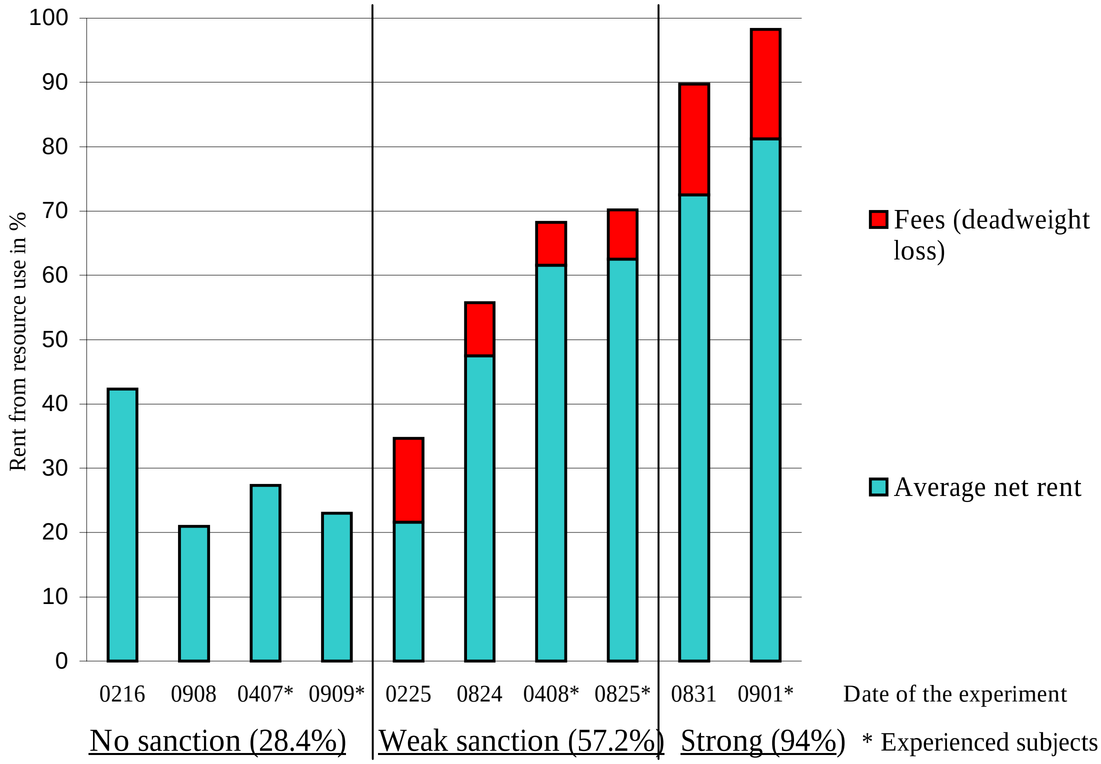


Figure 4: AVERAGE GROUP USE BY EXPERIMENTAL TREATMENT

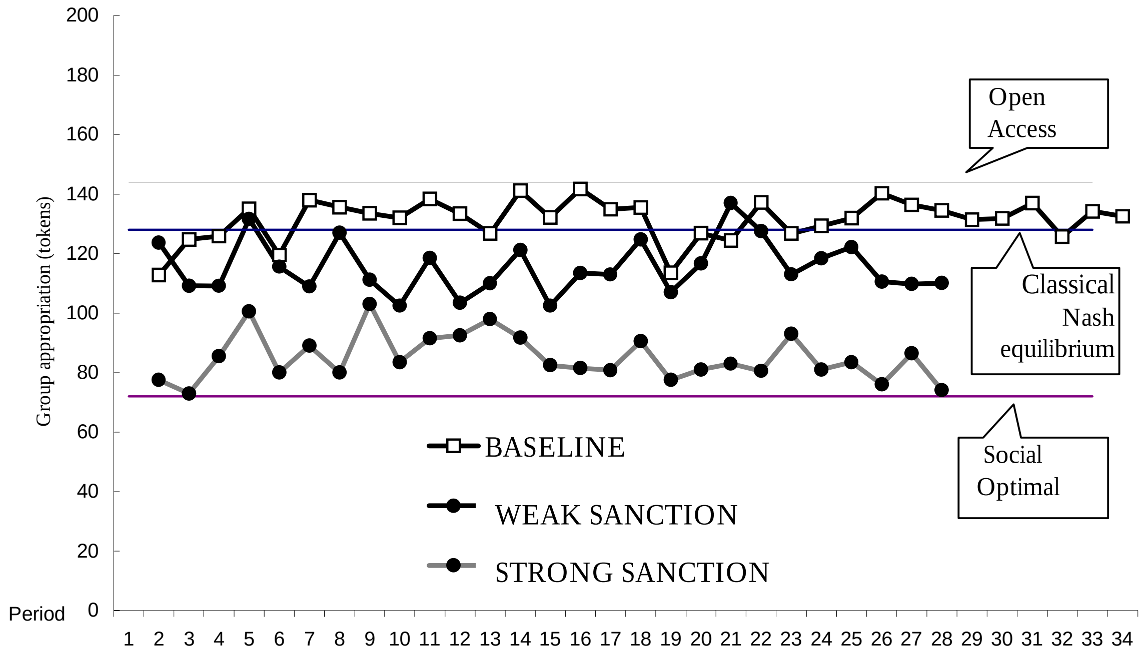
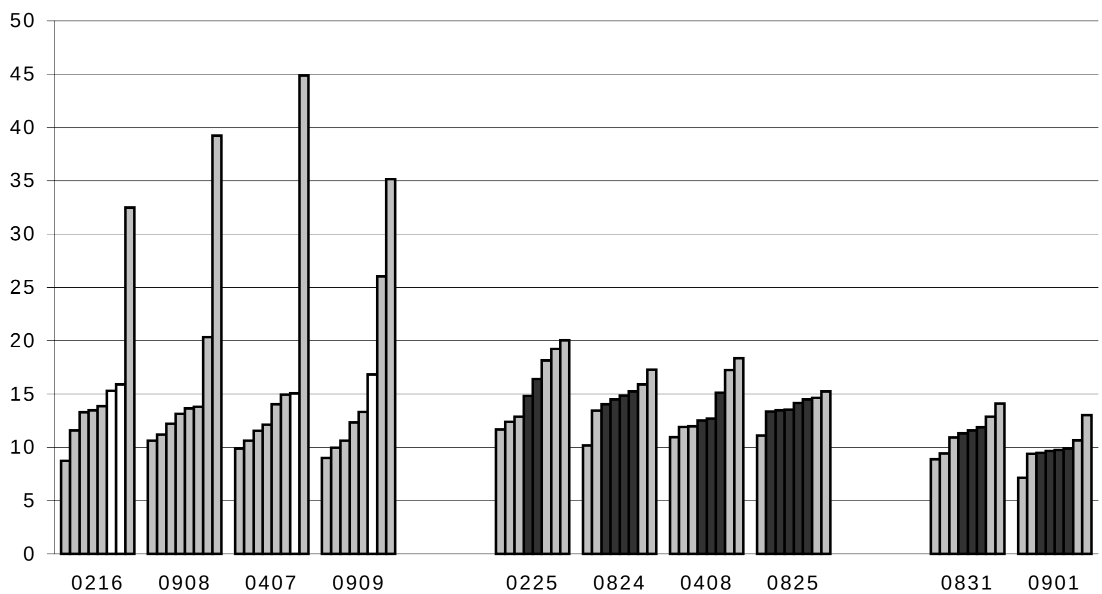


Figure 5: AGENT AVERAGE USE LEVELS (tokens)



Notes: Compare to the individual classical Nash equilibria: $x_i=16$ *for no sanction and weak sanction designs and* $x_i \approx 8.9$ *for strong sanction design. The white bars in the no-sanction experiments indicate the agents whose behavior is not statistically different from the classical Nash equilibrium at 0.05 level. The darker colored bars in the sanction experiments indicate the group of median agents that are not significantly different one from the other at 0.05 level.*

Table 1: MONITORING AND SANCTIONING INSTITUTIONS

	CASARI and PLOTT (2000) [This study]	**MOIR (1998)**	**OSTROM et al (1994)**	**FEHR and GATCHER (1999)**
Environment:	**Common-pool Resource**	Common-pool Resource	Common-pool Resource	Public Goods Provision
MONITORING (SEARCH)				
• *Monitoring Fee*	**Fixed fee for each request**	Variable fee for each request	None	None
• *Are all individual use levels (investment levels) revealed?*	**No, only if somebody in the group requests it**	No, only if the agent requests it	All use levels are public; all agent histories are public	All use levels are public; no individual history is available
SANCTIONING				
Targeted agent:				
• *Amount of the fine*	**In a fixed proportion of over-use**	Subjective choice of inspector (variable upper bound)	Subjective choice of inspector (fixed upper bound)	Subjective choice of inspector (up to 100% of period earnings)
• *Condition for inflicting the fine*	**If over-use occurred**	If over-use occurred	Subjective	Subjective
• *Multiple fines on the same action*	**No**	Yes	Yes	Yes
• *Identity of targeted agent*	**Publicly known after fine**	Publicly know after fine	Unclear*	Known only to targeted and inspecting agent
Inspecting agent:				
• *Fee (cost of administering the fine)*	**Included in monitoring fee**	Proportional to the amount of the sanction	Proportional to the amount of the sanction	More than proportional to the amount of the sanction
• *Who receives the fine*	**Inspector**	Experimenter	Experimenter	Experimenter
• *Limits to requests of sanctions per period*	**None**	Limited to the budget of the inspector	Each agent is limited to a single request	Unclear*
• *Identity of requesting agent*	**Not revealed**	Not revealed	Not revealed	Not revealed*

Notes: (*) This feature was not explicitely described in the papers. Monitoring is always perfect (i.e. there is truthful revelation of the action). In Ostrom(1992) and Fehr and Gatcher (1999) agents can sanction each other but there is really no monitoring device, since the individual actions are automatically revealed to everybody at the end of each period. Moir(1998) introduces two distinct decisions, first to monitor an agent and then to eventually sanction her. We have compacted them in a single decision: to inspect an agent or not. An inspection uncovers another agent's action and automatically inflicts a sanction if some conditions are met.

Table 2: EXPERIMENTAL TREATMENTS

Experiments	NO SANCTION				WEAK SANCTION				STRONG SANCTION	
Date	0216	0908	0407	0909	0225	0824	0408	0825	0831	0901
Sanctions	No	No	No	No	Yes	Yes	Yes	Yes	Yes*	Yes*
Experience	No	No	Yes	Yes+	No	No	Yes	Yes+	No	Yes+
Number of rounds	32^	32	33	32	27	27	27	27	27	27
Period endowment (tokens)	4	4	4	0	4	4	4	0	0	0
Conversion rate ($ per franc)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03

Notes:

Date Experiments were done at the California Institute of Technology in 1998

Sanctions "No" is a no sanction experiment;
"Yes" means that a monitoring and sanctioning device was added to the no sanction experiment;
"Yes*" indicates a different set of sanctioning parameters (see Section 5.3 for details)

Experience "No" means that no subject has ever participated in this type of experiment before;
"Yes" means that all the subjects have already participated in this type of experiment (on Dec 9, 1997 at the earliest);
"Yes+" means that all the subjects have participated the day before in this type of experiment with the same group of people

No. of rounds Number of effective rounds of interaction, which excludes two practice rounds;
(^) On 0216 a paper copy of the "Return from investment" table was handed to the subjects between the 10th and the 11th round instead of before the 1st round. During the whole experiment the table was projected on the wall of the room.

Period endowment The endowment E indicates the number of tokens given each period to each subject and is adjusted for the sole purpose of rescaling the minimum earnings of the subject (default earnings when she chooses not to use the common-pool resource). The endowment level E could be modified independently from the upper limit in the individual use of the common-pool resource $\hat{x}$ that was always kept at the same level, $\hat{x}$ =50 (more in Section 2).

Table 3: SUMMARY TABLE FOR USE DECISIONS

Experiments	**NO SANCTION**				**WEAK SANCTION**				**STRONG SANCTION**	
Date	0216	0908	0407	0909	0225	0824	0408	0825	0831	0901
Sanctions	No	No	No	No	Yes	Yes	Yes	Yes	Yes*	Yes*
Experience	No	No	Yes	Yes+	No	No	Yes	Yes+	No	Yes+
Number of rounds	32^	32	33	32	27	27	27	27	27	27
Period endowment (tokens)	4	4	4	0	4	4	4	0	0	0
Conversion rate ($ per franc)	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.04	0.03	0.03
GROUP USE										
Average	124.71	134.17	133.08	133.31	125.60	115.44	110.81	110.04	91.07	79.07
Classical Nash equilibrium	*128*	*128*	*128*	*128*	*128*	*128*	*128*	*128*	*71.11*	*71.11*
Minimum	100	85.5	121.5	87	87.3	87	92.5	90	74	69
Maximum	154	161	149.5	167	186.8	160	154.7	137	126	95.5
Standard deviation (Sd)	14.84	15.49	6.01	15.46	23.13	20.57	12.15	10.20	13.22	6.50
First half Sd/Second half Sd	4.52	1.68	2.59	0.79	0.92	0.83	2.57	1.46	2.18	0.85
EVOLUTION OF GROUP USE OVER TIME (Ashenfelter-El Gamal model)										
- Starting point	105.69	97.72	122.37	131.90	147.86	106.02	118.44	105.88	93.79	63.85
- Asymptote	133.96				114.78				86.13	
[0.95 confidence interval]	[130.96, 136.57]				[110.51, 119.06]				[82.23,90.02]	
GROUP EFFICIENCY (% of maximum rent)										
Average Rent	42.29	20.97	27.36	23.00	34.67	55.74	68.20	70.15	89.73	98.24
First 25 periods	*42.48*	*23.74*	*27.13*	*22.27*	*32.43*	*52.71*	*68.94*	*70.75*	*89.29*	*98.14*
Last 2 periods (after announce.)	*54.23*	*1.28*	*28.21*	*41.06*	*62.68*	*93.58*	*58.95*	*62.62*	*95.29*	*99.47*
INDIVIDUAL AVERAGE USE LEVELS										
Lowest average user	8.8	10.6	9.9	9.0	11.7	10.2	11.0	11.1	8.9	7.1
Highest average user	32.5	39.2	44.8	35.2	20.0	17.3	18.4	15.3	14.1	13.0
Gini coefficient of average agent uses	0.195	0.262	0.234	0.265	0.109	0.099	0.072	0.044	0.078	0.077
Rank correlation $1^{st}/2^{nd}$ half	0.917	0.902	0.961	0.966	0.907	0.892	0.926	0.872	0.823	0.858

See notes of Table 2

Table 4: USE AND INSPECTION ACTIONS

		WEAK SANCTION				STRONG SANCTION			
		Inspected?				Inspected?			
		No	Yes	*Totals*		No	Yes	*Totals*	
CAN YOU INSPECT THE ACTION WITH PROFIT?	No, $\vartheta<1$	220	162	*382*	*44.2%*	2	108	*110*	*25.5%*
	No, $\vartheta\geq1$	152	114	*266*	*30.8%*	2	33	*35*	*8.1%*
	Zero	20	37	*57*	*6.6%*	0	0	*0*	*0.0%*
	Yes	27	132	*159*	*18.4%*	0	287	*287*	*66.4%*
	Totals	*419*	*445*	*864*	*100%*	*4*	*428*	*432*	*100%*
		48.5%	*51.5%*	*100%*		*0.9%*	*99.1%*	*100%*	

Notes: No agent will request an inspection with a reward parameter $\vartheta<1$ in both the classical and other-regarding agent models. The reward parameter ϑ is below 1 when $x_j<12.5$ with weak sanctions and $x_j<7.875$ with strong sanctions. Inspecting is profitable when $x_j>16$ with weak sanctions and when $x_j>9$ with strong sanctions.

Table 5: SUMMARY TABLE FOR INSPECTION DECISIONS

Sanction Experiments	WEAK				STRONG	
Date	0225	0824	0408	0825	0831	0901
WELFARE ANALYSES	(% of the maximum rent)					
(1) Fees (deadweight loss)	13.04	8.24	6.64	7.68	17.20	17.04
(2) Fines (transfers)	14.01	8.90	6.49	6.19	43.39	28.44
Net Rent (Rent – Fees (1))	21.63	47.49	61.56	62.47	72.53	81.20
Inspection balance ((2) – (1))	1.0	0.7	-0.1	-1.5	26.2	11.4
ANALYSIS BY ACTIONS						
Actions inspected on total	75.5%	47.7%	38.4%	44.4%	99.5%	98.6%
Ratio of inspections undergone over the number of zero or positive balance inspections	2.17	2.29	1.48	2.40	1.52	1.46
Inspection “errors” on total actions	47.7%	34.3%	25.9%	32.4%	34.3%	31.0%
Of which:						
Type I error *(share of potentially profitable inspections not requested)*	0.098	0.167	0.239	0.192	0.000	0.000
Type II error *(share of potentially non-profitable inspections that have been requested)*	0.695	0.398	0.281	0.369	0.987	0.957

Notes: Total number of actions in an experiment: 216; maximum rent from use for the group is 324 francs per period; Balance of an inspection is defined from the standpoint of the agent who asked to inspect: fine collected minus fee paid. Inspection "errors" is in quote because strictly speaking they are mistakes only from the point of view of a self-interested agent.

Table 6: SPITEFUL AGENTS INSPECT MORE THAN ALTRUISTIC AGENTS

OLS regression	**WEAK sanctions** Coefficient	p-value	**STRONG sanctions** Coefficient	p-value
Dependent variable:	Total number of requests of inspections per period			
Sample size (without median users):	486		243	
Independent variables:				
Highest users (dummy variable)	0.34	0.015	-1.23	0.000
Period use of the other agents (x_{-i})	0.06	0.000	0.03	0.159
Constant	-5.42	0.000	1.58	0.366

Notes: The classical model predicts insignificant coefficients for the highest users dummy variable. See Figure 5 to identify the median users whose actions were excluded from the regressions.

Table 1A: COMPARISON BETWEEN OUR DESIGN AND THOSE OF WGO

	OUR DESIGN (E=4)				**WGO** (1990)			
	SO	NASH	OA	MAX	SO	NASH	OA	MAX
Total group use (tokens)	72	128	144	400	36	64	72	200
Symmetric individual use (tokens)	9	16	18	50	4.5	8	9	25
Individual earnings per period (in francs)	50.5	26	10	-140	165.5	141	125	-675
Cost of tokens (in francs)	-12.5	-30	-35	-115	102.5	85	80	0
Gross Return (in francs)	63	56	45	-25	63	56	45	-675
Individual earnings per period ($)	2.02	1.04	0.4	-5.6	1.655	1.41	1.25	-6.75

Notes: SO=Social optimum, NASH=Classical Nash equilibrium, OA=Open access, MAX= Maximum use allowed. WGO means Walker, Gardner and Ostrom (1990).

Table 2A: SUMMARY TABLE FOR WGO

Experiments	**NO SANCTION**		
Experiment number	1	2	3
Experience	Yes	Yes	Yes
Number of periods	20	20	20
Period endowment	50	50	50
Conversion rate ($ per franc)	0.01	0.01	0.01
GROUP USE			
Average	138.3	147.5	136.6
Classical Nash equilibrium	*128*	*128*	*128*
Minimum	108	84	116
Maximum	188	230	176
Standard deviation (Sd)	23.25	31.59	18.30
First half Sd/Second half Sd	1.58	2.22	1.56
GROUP EFFICIENCY	*(% of*	*maximum rent)*	
Average Rent	5.30%	-28.24%	13.36%

Notes: Original data have been rescaled (i.e. multiplied by two) to make the comparison easier with Table 3. From Walker, Gardner and Ostrom (WGO, 1990).