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Income Inequality and Cooperation in Common Pools*

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Abstract

There is an intriguing mixture of evidence regarding the effect of economic inequality on common-pool resource management. Similarly, there is a number of different theories trying to explain diffrent parts of the evidence. In this paper, I show that if utility is assumed to be S-shaped, non-cooperative game theory can be used to explain the evidence. When utility is S-shaped, income inequality does have a negative effect on cooperation, except at very low income levels, and makes an uneven distribution of the gains from cooperation efficient. The model also explains why sometimes the poor and sometimes the rich should get the larger share of the benefits from cooperation. In the light of this model, alms-giving, proportional distribution of gains, unequal input of labor and even a certain amount of free-riding can be seen as efficient means of enabling cooperation.

Key words: Common-Pool Resource; Income Inequality; Non-linear Utility; Poverty; Prisoners' Dilemma Game.

JEL Classification: C72; I39; O13; O17; Q20.

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1 Introduction

There is a rather intriguing mixture of evidence and theories regarding the management of common-pool resources where users are heterogeneous. Focussing on irrigation systems, both Lam (1998) and Dayton-Johnson (2000a) find that income inequality has a negative effect on cooperation, in the sense that systems with more income inequality tend to be less well maintained. Others, for example Wade (1988), have found inequality to be conducive to cooperation. There is also evidence that when income is unevenly distributed, so are the gains from cooperation. Dayton-Johnson (2000b) finds inequality to be the main explanatory factor for having proportional, rather than equal, rules for distributing the costs and benefits of using the common resource. In Cardena's (2003) common-pool resource field experiment, real wealth inequality had a negative effect on experimental cooperation. Although many studies find that the richer users get the larger share of the gains from the cooperative efforts,[1] Wade (1988), found that the richer users were sometimes those contributing more and André and Platteau (1998) give evidence from Rwanda that the poor may sometimes cooperate less. Thus, as Lam (1998) comments, it is not necessarily the poor farmers that are disadvantaged, and not necessarily the rich ones who refuse to cooperate.

While the empirical evidence shows that it is sometimes the rich and sometimes the poor that take a larger share of the benefits from cooperation, different theories are, so far, used to explain different parts of the evidence. For example, differences in bargaining power is used as an explanation why the poor contribute more than the rich,[2] while a greater gain from cooperation for the rich is sometimes used to explain why they may contribute more than the poor and why income inequality may be conducive to cooperation.[3] An exception is Bardhan and Dayton-Johnson (2002) who present a model in which the relationship between asset inequality and cooperation is U-shaped. Dayton-Johnson (2003) give a more extensive overview of different studies of heterogeneity and cooperation.

The purpose of this paper is to develop a more coherent theoretical explanation for the empirical evidence. The theory presented here assumes that agents are identical in all aspects other than their consumption level. Thus,

[1] Agrawal (1999).

[2] Both Lam (1998) and Dayton-Johnson (2000b) refer to this explanation. Ostrom and Gardner (1993) discuss bargaining between head- and tail-enders of irrigation systems.

[3] See, for example, Olson (1965) and Wade (1988).

income inequality is not reflected in differences in bargaining power, opportunity cost of labor, etc. What drives the results is instead the assumption that utility is non-linear. In developing countries, where the users are poor and often lack access to markets, there is a strong connection between income, consumption and health. In such a setting, Dasgupta's (1993) description of health as an S-shaped function of the body mass index is applicable.[4] Since health is of major importance to utility, it is arguable that utility is an S-shaped function of income.[5]

The management of the common-pool resource is analysed as a repeated prisoners' dilemma game, and inequality among agents is shown to lead to a difference in their critical discount factors. Hence, each agent's ability to commit to cooperation depends on total income as well as its distribution. The analysis shows that inequality is indeed an obstacle to cooperation in most cases. When the users are relatively rich, it is the richest that cannot commit and when the users are poor, it is the poorest. If the users are extremely poor, however, inequality may actually facilitate cooperation.

The intuition runs as follows: With a non-linear utility function, the marginal utility of a certain action (to cooperate or deviate) varies along the utility function. The more convex is the utility function, the higher is the marginal benefit of increased consumption (gained by deviating) and the smaller is the marginal loss of decreased consumption (lost when being punished for deviating). Thus, the more convex is the utility function, the greater is the temptation to deviate from cooperation, and the more difficult is it for users to commit to cooperation. In other words, the critical discount factor is increasing in the convexity of the utility function. With an S-shaped utility function, making the distribution of consumption more unequal will change the users' critical discount factors. Unless they are on either side of the most convex point of the utility function, this will increase the critical discount factor of at least one them, thus decreasing the chances of cooperation.

The problem caused by inequality can be remedied if the agent with the commitment problem can be made to value the gains from cooperation more highly. If the poor user cannot commit, he could be made somewhat richer. There is thus a role for alms-giving, as a way for the rich of keeping the poor from disturbing cooperation. There is also a role for a proportional

[4] The body mass index (BMI) is defined as weight/height^2. See also Shetty and James (1994).

[5] See Ternström (2002a).

distribution of the gains from cooperation, as a way of sweetening the deal for the rich when they are the ones unable to commit to cooperation. An interesting aspect is that this can also be achieved by allowing a certain amount of free-riding by the rich. Finally, there is a role for Robin Hood, when inequality has made it difficult for both rich and poor agents to commit to cooperation.

The closest theoretical contributions are Spagnolo (1998), who discusses the effects of concave utility in non-cooperative games and Ternström (2002a), who analyses the effects of S-shaped utility on cooperative management of common-pool resources. Baland and Platteau (1999, 1998 and 1997) investigate a number of factors that may determine whether inequality will be good or bad for cooperation. Grossman (1995) comes to conclusions similar to mine, but uses a quite different model. She finds that under certain circumstances, voluntary redistribution, in the form of wage subsidies or lump-sum transfers from the propertied class to the working class, can be an optimal response to the threat of extra-legal appropriation. In the model introduced here, this would correspond to the rich giving the poor a larger share of the benefits from cooperation or making an income transfer to them, to make the poor able to commit to cooperation.[6]

Section 2 introduces the model and Section 3 explains how inequality affects cooperation. Section 4 present ways of achieving cooperation despite inequality and Section 5 concludes.

2 The Model

I model the management of a common-pool resource as a repeated prisoners' dilemma game, and assume that there are two agents, one richer, R, and one poorer, P. Let K_i denote agent i's income from sources external to the common-pool resource. Agent R gets a higher income from external sources than agent P, that is $K_{\text{R}} > K_{\text{P}}$. Apart from the external income, the agents are identical. I assume here that their external income is additive to their use of the common-pool resource, but it could also be multiplicative or a

[6] There are also connections to the IO-literature, where heterogeneity is shown to be an obstacle to cooperation, see e.g. Tirole (1997) and Rotschild (1999), and to the literature on private provision of public goods; see, for example, Warr (1983) and Bergstrom et.al. (1986).

combination of both.[7] When the external income is additive, it represents a source of income that is independent of the use of the common-pool resource, except that it affects the agent's consumption level.[8]

In every period, each agent i chooses an action $a_i \in \{c, d\}$, where c denotes cooperation and d defection in the use of the common-pool resource. The agents' actions are reflected in π_{a_i,a_j}, with $\pi_{d,c} > \pi_{c,c} > \pi_{d,d} > \pi_{c,d}$ and $2\pi_{c,c} \geq \pi_{d,c} + \pi_{c,d}$ by assumption. The size of the common-pool resource is indicated by α, and the total consumption of agent i, C_i, is expressed as

$$C_i = \alpha\pi_{a_i,a_j} + K_i. \tag{1}$$

The analysis is limited to finding out whether a trigger strategy, known to generate the maximum amount of cooperation in ordinary repeated prisoners' dilemma games,[9] can sustain cooperation in this setting. I thus assume that the agents employ a trigger strategy, according to which they cooperate as long as no one has ever deviated. If an agent has ever defected, both agents will defect forever.[10] Under these assumptions, the benefit to agent i from cooperating is

$$\sum_{t=0}^{\infty} \delta^t U\left(\alpha\pi_{c,c} + K_i\right), \tag{2}$$

while if he deviates, he gets

$$U\left(\alpha\pi_{d,c} + K_i\right) + \sum_{t=1}^{\infty} \delta^t U\left(\alpha\pi_{d,d} + K_i\right). \tag{3}$$

An agent will choose to cooperate if and only if

$$\sum_{t=0}^{\infty} \delta^t U\left(\alpha\pi_{c,c} + K_i\right) \geq U\left(\alpha\pi_{d,c} + K_i\right) + \sum_{t=1}^{\infty} \delta^t U\left(\alpha\pi_{d,d} + K_i\right). \tag{4}$$

[7] See Ternström (2002a) for a comparison of additive and multiplicative external income.

[8] When multiplicative, the external income increases the productivity of the common-pool resource by a factor $e\left(K_i\right)$, and could be caused by differences in, for example, the use of chemical fertilisers in the case of irrigation systems, or additional food in the case of grazing.

[9] See Abreu (1986, 1988).

[10] This is a simplified and more cruel version of reality, where sanctions are often graduated (see.e.g. Ostrom 1990). It does, however, fill the purpose of theoretically analysing the effects of income inequality when utility is non-linear.

From this expression, we derive the minimum discount factor at which agent i can credibly commit to cooperation, that is, his critical discount factor,

$$\delta_i^*\left(\alpha, K_i\right) = \frac{U\left(\alpha\pi_{d,c} + K_i\right) - U\left(\alpha\pi_{c,c} + K_i\right)}{U\left(\alpha\pi_{d,c} + K_i\right) - U\left(\alpha\pi_{d,d} + K_i\right)}. \tag{5}$$

When agents are identical in all respects, that is, if $K_i = K_j$, they will have identical critical discount factors. Furthermore, even if there is inequality, they will have identical critical discount factors, if utility is linear. Thus, in the special case of linear utility, inequality *per se* will not affect the scope for cooperation.

3 Negative Effects of Inequality

As Spagnolo (1998, 1996) has shown, concave utility makes it easier for identical individuals to cooperate. The reason is that the more concave is the utility function, the smaller is the utility gained from deviating, and the larger is the utility lost when being punished for it. Ternström (2002a) extends this analysis to characterise the scope for cooperation between identical individuals with S-shaped utility functions. Essentially, this earlier analysis characterises the critical discount factor for any given individual, given his or her wealth. Figures 1 and 2 below illustrate the relationship analysed in Ternström (2002a). Equation (6) and Figure 1 depict a utility function whose shape closely mirrors the relationship between health and BMI suggested by Dasgupta (1993).[11]

$$U\left(C\right) = \left[1 + \frac{1}{1+C} + e^{-\gamma\left(C - \text{MMI}\right)}\right]^{-1}, \tag{6}$$

[11] See Ternström (2002a) for more details.

which, with MMI $= 16.5$, and $\gamma = 1.4$, is depicted below.

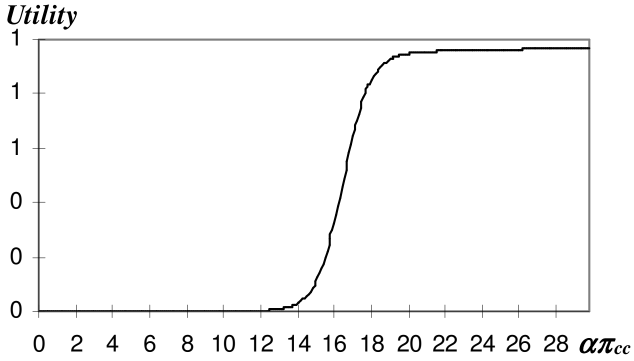
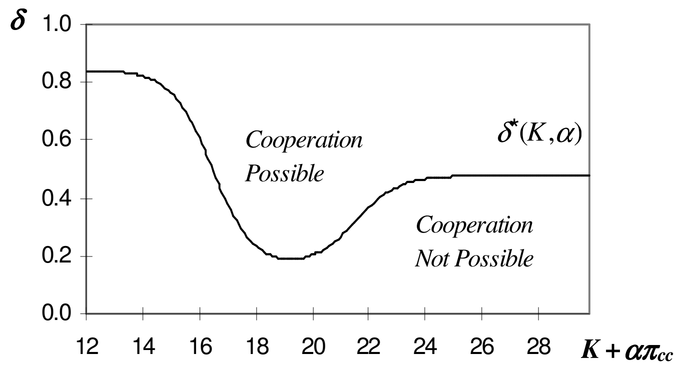


Figure 1. Utility as an S-shaped Function of Income. Source: Ternström (2002a).

The convexity of this function is increasing up to a consumption level corresponding to a BMI of approximately 15, where the function is maximally convex. The convexity then decreases until the consumption level corresponding to a BMI of approximately 18.5, where the function is maximally concave.[12] The function then increases in convexity once more as the utility function becomes asymptotically linear. Figure 2 shows the corresponding critical discount factor.



[12] The specification of the function is an approximation of the relationship suggested by Dasgupta. The figures are to be seen mainly as an illustration..

Figure 2. The critical discount factor when utility is S-shaped, the return from the common-pool resource is too low to survive on ($\alpha\pi_{c,c} = 12$) *and* $\pi_{d,c} = 1.1\pi_{c,c}$ *and* $\pi_{d,d} = 0.9\pi_{c,c}$. *Source Ternström (2002a).*

The two figures illustrate that the critical discount factor is higher, the more convex is the utility function.[13] Since cooperation requires the discount factor to be greater than the largest of the agents' critical discount factors, the present analysis simply answers the following question: How is the largest critical discount factor affected by income inequality?

If the largest critical discount factor increases with inequality, then inequality will have decreased the scope for cooperation. If, on the other hand, the largest critical discount factor decreases as a result of inequality, then inequality has improved the chances for cooperation. From Proposition 1 in Spagnolo (1998, 1996) and Proposition 1 in Ternström (2002a) we know that the critical discount factor is increasing in the convexity of the utility function. Let $\widehat{C} = (C_{\mathrm{P}} + C_{\mathrm{R}})$, define $\overline{C}$ as the consumption level where $U(C)$ is maximally convex, and $\underline{C}$ as the consumption level where $U(C)$ is minimally concave. Then the above question can be answered as follows:

Proposition 1 ***Proof.***

Proposition 2 *If* $\overline{C} < C_{\mathrm{P}} < C_{\mathrm{R}}$, *then a redistribution of the total consumption that makes the distribution of consumption more unequal will make cooperation more difficult.*

■

Proof. *Increasing inequality while keeping* $\widehat{C}$ *constant implies increasing* C_{R} *and decreasing* C_{P}. *When* $\overline{C} < C_{\mathrm{P}} < C_{\mathrm{R}} < \underline{C}$, *the critical discount factor is decreasing* δ^*_{R} *and* δ^*_{P} *will increase further if* C_{P} *decreases. When* $\overline{C} < C_{\mathrm{P}} < \underline{C} < C_{\mathrm{R}}$, δ^*_{P} *is decreasing in consumption and* δ^*_{R} *is increasing in consumption. Hence, both* δ^*_{P} *and* δ^*_{R} *will increase from increased inequality. Finally, when* $\underline{C} < C_{\mathrm{P}} < C_{\mathrm{R}}$, *the critical discount factor is increasing in consumption. Hence,* $\delta^*_{\mathrm{R}} > \delta^*_{\mathrm{P}}$ *and* δ^*_{R} *will increase further if* C_{R} *increases.* ■

The result is easily understood by considering Figure 2. To the right of its maximum (corresponding to $\overline{C}$), the critical discount factor is U-shaped.

[13] Of course, the relative size of the material payoffs of different actions also affects the exact location of the maximum and minimum of the critical discount factor.

On the left-hand side of this U, the critical discount factor is decreasing in income, thus the poorest agent will have the highest critical discount factor. On the right-hand side of the U, i.e. above $\underline{C}$, the critical discount factor is increasing in income and here, the richest agent will have the highest critical discount factor. Moving the agents' income levels apart will make at least one of them move further upwards along a side of the U, which will inevitably lead to an increase in the highest critical discount factor. Furthermore, if the agents' income levels are on either side of the bottom of the U (the point of minimally convex utility), both agents' critical discount factors will increase when income inequality increases.

At very low income levels, the shape of the critical discount factor at the lowest consumption levels depends on whether the two income sources are additive or multiplicative.[14] If they are additive, the critical discount factor is asymptotically linear as consumption decreases below $\widehat{C}$, but if they are multiplicative, we have an inverted U-shape at low consumption levels. In this case, increased inequality may move both agents further down the sides of the inverted U, thereby decreasing their critical discount factors. At even lower income levels, with both agents' incomes to the left of $\widehat{C}$, the critical discount factor will once more be increasing in the income level and thus, the richer agent will have the higher critical discount factor.

It also follows from the propositions referred to above that if one agent is below the inflexion point of the utility function (thus having convex utility) and the other agent is above it (and has concave utility), it will always be the poorer agent who has the highest critical discount factor.

Note that we have assumed the individual discount factor to be constant and identical for the two agents.[15] We should also be aware of there being what we might call a substitution effect. When the share of an agent's income from other sources than the common-pool resource increases, the relative difference between material payoffs decrease, making the agent relatively less sensitive to the outcome of the game over the common-pool resource. This implies that the critical discount factor becomes less sensitive to changes in

[14] Again, see Ternström (2002a) for a more thorough comparison of these two cases.

[15] It may be argued that because of their different consumption levels, agents have different degrees of impatience. Thus, a poorer agent could have a lower discount factor than a richer, more patient, agent. If the poor agent has the highest critical discount factor, this would make cooperation even more difficult. In the opposite case, with the rich agent having the highest critical discount factor, it would instead increase the chances of cooperation.

the total consumption. In other words, the critical discount factor in Figure 2 becomes smoother.[16]

Having thus established the effects of income inequality on cooperation when utility is S-shaped, I proceed to exploring the practical consequences. First of all, what is the rationale for an S-shaped utility function? Here, I am focussing on common-pool resources located in the poorer parts of the world and whose users are poor enough that their health is directly dependent on their consumption level and thus, their income level. Under such circumstances, it is not unreasonable to assume that the users of the common-pool resource lack access to markets for goods and credit, and that storage facilities are lacking. I also assume health to be a strong component in the users' utility function. Dasgupta's (1993) suggested S-shaped relationship between the body mass index and the probability of remaining in good health is supported by the empirical evidence presented in Shetty and James (1994). A BMI of about 12 is required to stay alive.[17] This relationship is well approximated by the utility function presented in Equation (6).

When translating the above relationship into a utility function (thus making the simplifying assumption that health is the only argument in the utility function), I can make predictions about the effects of inequality at different income levels (measured as the BMI-equivalent of consumption). If we assume that the agents have equally large consumption levels at the outset, a mean preserving spread in income distribution will decrease the chances of cooperation if their initial BMI is sufficiently above or below 15. At a BMI equal to 15, increased inequality could actually improve the scope for cooperation in some cases. However, as Baland and Platteau (1996) points out, when the consumption level becomes so low that there is a serious threat of not surviving, the discount rate of future incomes may become infinite. Thus, we should be very careful in interpreting the results for the lowest BMI levels. Even though the critical discount factor is decreasing here, the individuals' discount factors may approach zero, thus making cooperation impossible anyway.

If the agents' consumption levels, measured in BMI, are between about 15 and 20, the poor agent will be the one with a commitment problem. According to the 2004 World Development Indicators,[18] in 1999-2001 24 percent of

[16] See Ternström (2002a) for further discussion.

[17] According to Shetty and James (1994), studies have shown a BMI of 13 to be required for men, while the limit for women seems to be 11.

[18] The World Bank (2004).

the population in low income countries were undernourished, implying that they had a BMI below 18.5. Shetty and James (1994) present data for the distribution of BMI in a range of countries, suggesting that less than a couple of percent of adults had a BMI below 16 and less than 20 percent had a BMI between 16 and 18.5. In India, however, almost half the adults had a BMI below 18.5, and 10 percent a BMI below 16. This suggests that in many cases, users of a common-pool resource have a fairly low critical discount factor, but that the critical discount factor of both rich and poor will increase as a result of increased inequality.

When the users' consumption levels correspond to BMIs above 20, we would expect the relatively richer agent to be the one preventing cooperation. When considering the average BMI of large groups of people, it should be noted that users of common-pool resources are often the poorer ones in a society.[19] Furthermore, there is likely to be a correlation between the type of common-pool resources and the users' income level. For example, while users of common-pool irrigation systems have access to land for cultivation, users of other kinds of common-pool resources may be landless, and thus poorer.

Having established that, and how, inequality can adversely affect the chances of cooperation in a common pool, I shall proceed to explore how cooperation can be achieved despite inequality.

4 Cooperation under Inequality

In the above, I concluded that cooperation will fail if either of the agents can not commit to cooperation because of a too high critical discount factor. However, this is not necessarily the end of the story. As suggested by the empirical evidence, there are a number of ways of avoiding the non-cooperative outcome, even if there is inequality. If there is enough difference between the individual discount factor and the lowest critical discount factor, there is scope for improvement. If the potential cooperator can somehow make a sacrifice that sufficiently decreases the potential deviator's critical discount factor, without increasing his own critical discount factor too much, cooperation will be possible. How to achieve this is the topic of this section.

There are mainly two ways of facilitating cooperation in the presence of inequality. First, external income can be redistributed, thereby moving

[19] See e.g. Jodha (2001).

the agents along the utility curve and changing their marginal valuations of cooperating versus defecting. Second, the rules deciding how to distribute the gains from cooperation can be changed, changing the relative gains from cooperating versus defecting in physical terms.

4.1 Redistribution of External Income

It follows immediately from Proposition 1 that when inequality is a problem, the chances for cooperation can be improved by making the distribution of a given amount of external income more equal. The goal of such a redistribution is to fulfil what we can call a cooperation constraint,

$$\max\{\delta^{*\prime}_{\mathrm{P}}, \delta^{*\prime}_{\mathrm{R}}\} \leq \delta, \tag{7}$$

with the superscript $*\prime$ indicating the new critical discount factors. Whomever is the non-committant agent, this implies transferring income from the rich to the poor agent. However, this is an unnecessarily crude method, and it does not use the full potential for improvement. What we really need to achieve is to decrease the critical discount factor of one agent, agent D (D for deviating), to a level where

$$\delta^{*\prime}_{\mathrm{D}} \leq \delta, \tag{8}$$

If this can be done without changing the critical discount factor of agent C (C for cooperating), so much the better, since we know that this is already at a level conducive to cooperation. With this specification of the problem, it is important to remember that if agent D is the poorer agent, income should be transferred *to* him, while if agent D is the richer agent, income should be transferred *from* him.

What would such transfers look like in reality? Starting with the case when the poor agent is unable to commit ($\delta^{*}_{\mathrm{P}} > \delta$) and both agents are between the points of maximum convexity and maximum concavity ($\overline{C} < C_{\mathrm{P}} < C_{\mathrm{R}} < \underline{C}$), the important thing is that income is transferred to the poor. If this is not to affect the richer agent's income level, the transfer must be made from outside sources, such as aid targeted at the poor. If the transfer is made from the rich agent, it is important that the rich agent's income does not decrease too much, or the problem will be reversed. This puts a different perspective on the tradition of alms-giving. Instead of being motivated by altruism, it could be a way for the rich of increasing their own well-being by enabling the poor to commit to cooperation. The rich may also improve the situation for their poor co-users by offering favorable agreements on other areas of interaction, such as tenure-, sharecropping- or informal credit arrangements.

When the agents' consumption levels are on either side of the point of maximum concavity ($C_{\mathrm{P}} < \underline{C} < C_{\mathrm{R}}$), both δ^*_{P} and δ^*_{R} will decrease from a transfer of income from the rich to the poor. We may then again consider alms-giving from rich to poor users as a solution. If the users cannot achieve this transfer of income on their own, this is a situation where Robin Hood would for once be appreciated by both rich and poor.

Finally, when both agents' consumption levels are above the point of maximum concavity ($\underline{C} < C_{\mathrm{P}} < C_{\mathrm{R}}$), it will be the richer agent who has the commitment problem. In this case, the income transfer should still go from the rich. In this situation, alms-giving would have the negative side-effect of increasing critical discount factor of the poor agent, and donations to religious purposes, schools, etc. would be a better way of decreasing the income of the rich. Proportionate income taxes is yet another way to solve the problem. However, the solution suggested in Section 4.2 may seem more feasible when the rich have the commitment problem.

In the above discussion, I have implicitly assumed that transfers are made before the game over the common-pool resource begins. The transfer will then change the agent's valuation of his actions in such a way that cooperation becomes the preferred action. Thus the transfer can be completely unconditional on the actions chosen in the use of the common resource.[20] I have also implicitly assumed that the transfer is made every period. For this reason, the model is better suited to situations where transfers are part of long-term agreements on other areas of interaction, or are embedded in the norms of a society. Assuming that the transfer is made in each period rather than once and for all is also more reasonable in a setting where there is assumed to be no credit markets.

[20] Note the connection to side-payments in oligopolies. There, cooperation among heterogeneous firms involves side-payments and contracts regulating future output levels of the involved firms. Here, there will be no need for a contract conditioning the transfer on future cooperation. Once the transfer has been made, the cooperation of the recipient will follow voluntarily.

4.2 Redistribution of Cooperative Payoff

It is sometimes suggested that a proportional allocation of the output from a common-pool resource is less efficient than an equal allocation. In this section, I show that when there is inequality, this may be wrong. If the institutional characteristics of management, and not only the physical characteristics of the resource, are considered, an unequal distribution of net benefits may induce cooperation and can thereby result in a higher utility for all, than an equal distribution. Contrary to the last section, this section does not focus on removing the obstacle caused by income inequality, but rather on ways of achieving cooperation in the presence of inequality. Here, we want to increase agent D's relative benefit from cooperating. Note that it should now always be agent D that gets a larger share of the pie, irrespective of whether he is rich or poor.

In practice, the output from a common-pool resource is often distributed according to rules dictating who gets how much. If, for example, the agents are herders, they can allow one herder to put more animals onto the common grazing lands than the others, if they cooperate. If the agents are farmers using a common-pool irrigation system, they may agree on having different sizes of water outlets from the canal, or some farmers having longer time-slots for irrigation than others. In this way, the users can choose a combination of relative material payoffs that decreases the critical discount factor of those with a difficulty to commit to cooperation.

A theoretical analysis of this kind of behaviour should optimally involve the use of a continuous strategy space so that we could find the optimal distribution of the output in every period. However, in order to facilitate the theoretical analysis, I instead assume that the agents can decide to allow one party to occasionally take a larger share of the resource without punishment. That is, instead of always getting some more, he will sometimes get much more than the other agent. Depending on the whether agent D's utility is concave (or convex) in the relevant segment, this will under- (or over-) estimate the effect of the changed distribution.

I hence let this new strategy prescribe cooperation in all periods but every x'th, when agent D is allowed to deviate without punishment. On all other occasions, deviations are punished by reverting to non-cooperation. We thus still have a trigger strategy, although somewhat modified. In order to find out what it takes for this strategy to induce cooperation, we must study the effect on the two agents' critical discount factors.

Under the modified strategy, agent C's gain from deviating will be greatest in period x-1, since he will then have reaped the benefits from cooperation in as many periods as possible, while still having a gain to make from deviating. Agent D, on the other hand, will have most to gain from deviating in period x+1, when he has the longest stretch of low-payoff periods ahead. Thus, it is in these two periods that the critical discount factors will be highest, and when examining the modified strategy, I shall be focussing on these. Since I am considering the effect of moving part of the payoff from using the common-pool resource from one agent to the other, we must here always consider both agents' critical discount factors.

While the benefit from deviating remains the same as with the original trigger strategy, the benefit from cooperating will now be as follows. In period x-1, agent C's benefit from cooperating is

$$\sum_{t=0}^{\infty} \delta^{xt} \left[U\left(\alpha\pi_{c,c}+K_{\mathrm{C}}\right)+\delta U\left(\alpha\pi_{c,d}+K_{\mathrm{C}}\right)\right.$$
$$\left.+\delta^{2} U\left(\alpha\pi_{c,c}+K_{\mathrm{C}}\right)+\ldots+\delta^{x-1} U\left(\alpha\pi_{c,c}+K_{\mathrm{C}}\right)\right] \tag{9}$$

and in period x+1, agent D's benefit from cooperating is

$$\sum_{t=0}^{\infty} \delta^{xt} \left[U\left(\alpha\pi_{c,c}+K_{\mathrm{D}}\right)+\delta U\left(\alpha\pi_{c,c}+K_{\mathrm{D}}\right)\right.$$
$$\left.+\delta^{2} U\left(\alpha\pi_{c,c}+K_{\mathrm{D}}\right)+\ldots+\delta^{x-1} U\left(\alpha\pi_{d,c}+K_{\mathrm{D}}\right)\right]. \tag{10}$$

Writing the conditions for cooperation on the same form as Equation (4) and collecting terms, we get the following for agent C

$$\sum_{t=0}^{\infty} \delta^{xt}\left\{\sum_{z=0}^{x-1} \delta^{z} U\left(\alpha\pi_{c,c}+K_{\mathrm{C}}\right)+\delta\left[U\left(\alpha\pi_{c,d}+K_{\mathrm{C}}\right)-U\left(\alpha\pi_{c,c}+K_{\mathrm{C}}\right)\right]\right\}$$
$$\geq U\left(\alpha\pi_{d,c}+K_{\mathrm{C}}\right)+\sum_{t=1}^{\infty} \delta^{t} U\left(\alpha\pi_{d,d}+K_{\mathrm{C}}\right), \tag{11}$$

and for agent D

$$\sum_{t=0}^{\infty} \delta^{xt}\left\{\sum_{z=0}^{x-1} \delta^{z} U\left(\alpha\pi_{c,c}+K_{\mathrm{D}}\right)+\delta^{x-1}\left[U\left(\alpha\pi_{d,c}+K_{\mathrm{D}}\right)-U\left(\alpha\pi_{c,c}+K_{\mathrm{D}}\right)\right]\right\}$$
$$\geq U\left(\alpha\pi_{d,c}+K_{\mathrm{D}}\right)+\sum_{t=1}^{\infty} \delta^{t} U\left(\alpha\pi_{d,d}+K_{\mathrm{D}}\right). \tag{12}$$

From these equations, it is obvious that the change in strategies will increase the gain from cooperating, and thus result in a decreased critical discount factor, for agent D, but at the cost of an increased critical discount factor for agent C, whose gain from cooperating decreases.

Proposition 3 *Any change in strategies that makes cooperation possible will be voluntarily adhered to by both agents.*

Proof. Proof. Consider first agent D. By design, the modified strategy will give agent D more than he would by deviating, thus he will gain from the change in strategies. Agent C will get less than if cooperation had been possible under the old strategy, but since it was not, he will prefer the modified strategy if it gives him a higher utility than under non-cooperation, that is, if

$$\sum_{t=0}^{\infty} \delta^{xt} \left\{ \sum_{z=0}^{x-1} \delta^{z} U\left(\alpha \pi_{c,c} + K_{\mathrm{C}}\right) + \delta \left[U\left(\alpha \pi_{c,d} + K_{\mathrm{C}}\right) - U\left(\alpha \pi_{c,c} + K_{\mathrm{C}}\right) \right] \right\}$$
$$\geq \sum_{t=0}^{\infty} \delta^{t} U\left(\alpha \pi_{d,d} + K_{\mathrm{C}}\right). \tag{13}$$

Since non-cooperation gives less than deviating, we can conclude that agent C will also gain from the change in strategies. Hence, both agents will voluntarily agree to change the strategy. ■

How often agent D should be allowed to deviate, that is, how small x should be under the modified strategy, depends on how close the agents' critical discount factors are to the personal discount factor and on how much the agents gain or lose in the periods that deviation is allowed. Let $\Delta U_{\mathrm{C}}^{x}$ symbolise the change in the gain from cooperation of agent C in period x, and $\Delta U_{\mathrm{D}}^{x}$ the corresponding change for agent D, that is,

$$\Delta U_{\mathrm{C}}^{x} = U\left(\alpha \pi_{c,d} + K_{\mathrm{C}}\right) - U\left(\alpha \pi_{c,c} + K_{\mathrm{C}}\right) \tag{14}$$

and

$$\Delta U_{\mathrm{D}}^{x} = U\left(\alpha \pi_{d,c} + K_{\mathrm{D}}\right) - U\left(\alpha \pi_{c,c} + K_{\mathrm{D}}\right). \tag{15}$$

If ΔU_{i}^{x} is positive, that is if the gain from cooperating increases, the critical discount factor decreases and cooperation becomes more likely. The change in strategies will increase agent C's critical discount factor more, the smaller is x, and the larger is δ and $\Delta U_{\mathrm{C}}^{x}$. Naturally, the reason is that the smaller is x, the more frequently will agent C have to take a decreased payoff when cooperating, and the larger is $|\Delta U_{\mathrm{C}}^{x}|$, the larger is the loss when this occurs. Finally, the larger is δ, the more important are future payoffs to the agent. For agent D, the decrease in the critical discount factor will be larger, the smaller is x and the larger is δ and $\Delta U_{\mathrm{D}}^{x}$.

Given δ and ΔU_{i}^{x}, we can define $x_{\min}$, the smallest x under which agent C is able to commit to cooperation and $x_{\max}$, the largest x under which agent D is able to commit to cooperation. For the modified strategy to induce cooperation, $x_{\max} \geq x_{\min}$. The larger is $x_{\max} - x_{\min}$, the greater is the scope for finding an x that lies between the two. If there was initially considerable slack between agent C's personal and critical discount factors ($\delta - \delta_{\mathrm{C}}^{*}$ large), his payoff from cooperation can be considerably decreased without making it impossible for him to commit to cooperation. Given $\Delta U_{\mathrm{C}}^{x}$, this implies that deviations can be allowed fairly often, and that $x_{\min}$ will be quite small.

Similarly, if agent D was close to being able to commit to cooperation under the original strategy ($\delta_{\mathrm{D}}^{*} - \delta$ small), it only takes a small increase in the benefit from cooperation to make him able to cooperate and, given $\Delta U_{\mathrm{D}}^{x}$, $x_{\max}$ can be quite large. A large $x_{\max}$ and a small $x_{\min}$ mean that quite a large number of x's will make cooperation possible. In the opposite case, with agent C's critical discount factor close to his personal discount factor and agent D's critical discount factor far away from his personal discount factor, $x_{\max} - x_{\min}$ will be small and may even be negative. If $x_{\max} - x_{\min}$ is negative, it will not be possible to sustain cooperation, even if the strategy is changed.

Now, how would this look in reality? If we translate back into rules for allocating the net benefits from cooperation in each period, instead of every x'th period, a small x would, *ceteris paribus*, indicate a very uneven distribution of benefits, while a large x would indicate the opposite. Hence, the more uneven the distribution of benefits is, the more unequal should we expect the agents to be. In the light of the discussion above, the common practise of relating the distribution of water to the distribution of land in irrigation systems, makes perfect sense. When combined with a "one-man-per-household" rule for labor contribution,[21] we should strongly suspect that the richer agent was originally the one with the commitment problem.

Just as above, whether it is the poor or the rich agent that is agent D

[21] See Ternström (2002b).

will depend on the total income level as well as on its distribution. If both agents are above the point of maximum concavity, agent D will be the richer agent. Thus, in groups with a relatively higher average income level (both agents' BMI $\gtrsim 20$), we would expect that the rich are getting a larger share of the gains from cooperation, as in the example of irrigation systems above. Interestingly, we thus find that if it is the rich agent that cannot commit to cooperation, there are two seemingly opposite ways of improving the scope for cooperation - either by decreasing his income from external sources, or by increasing his share of income from cooperation.

The result is related to Dayton-Johnson's (2000b) findings. In his survey of Mexican farmers, Dayton-Johnson finds that user groups allocating the benefits from cooperating proportionally to land-holding size have a high level of inequality, a higher minimum parcel size and higher wages than groups with other distributive rules. Although the exact consumption level of the farmers is not revealed, FAO (2002) shows that only 5 percent of the Mexican population suffers from suffers from undernourishment. With such a small percentage, farmers with access to irrigation are unlikely to have a BMI below 20, and a distribution of the benefits from cooperation (water, in this case) that is proportional to land-holding size, is what we would expect given the analysis above.

If the agents' income levels are fairly low (BMI $\lesssim 20$), we would expect the poor to be getting a larger share of the benefits from cooperation, that is, a counter-proportional allocation. André and Platteau (1998) give empirical evidence from Rwanda of instances when poorer users were the ones unable to cooperate, and allowed to take a larger than equal share without punishment. Interestingly, the offenders were less benevolently treated if they were deviating for other reasons than from hunger. This occurred under circumstances of temporary and extremely low consumption levels. Since as much as 40 percent of the population in Rwanda suffer from undernourishment[22] and the evidence given by André and Platteau refers to the poorest individuals under very poor circumstances, this is in line with what we would expect from the results here. If we combine the results here with those of Ternström (2002a), indicating that a temporary decrease in the consumption level can be countered by a temporary relaxation of the rules for cooperation, this is in line with what we would expect. In times of a (temporarily) low average income, we would expect the poor to be the ones with a commitment problem

[22] FAO (2002)

and thus, those excused if breaking the rules.

Another interesting aspect of the results is that since the net benefit from cooperation consists of both costs and benefits, it can also be increased by decreasing the required contribution to maintenance efforts, for example. In the case where agent D is rich, allowing him a decreased contribution to maintenance can give a double dividend if it is *not* replaced by an increased contribution from agent C. First, the negative impact on agent C's ability to commit to cooperation will be avoided. Second, if the output from the resource depends on the amount of maintenance, less maintenance will imply less output. This will further decrease agent D's critical discount factor and, if agent C' income is also above the point of maximum concavity, this will decrease agent C's critical discount factor too. In the eyes of an outsider, this is likely to be interpreted as free-riding by the richer agent. In reality, it is a rational adjustment to the preconditions for cooperation.

5 Final Remarks

The main conclusion of this paper is that if utility is not linear, the management of common-pool resources is sensitive to income inequality.

The analysis easily generalises to more than two individuals. Unless the income interval includes BMI $\approx$ 15 or BMI $\approx$ 20, either the richest or the poorest individuals have the largest commitment problem. If BMI $\approx$ 15 is included in the income interval, there is scope for a class society among the poor. If BMI $\approx$ 20**,** it may be the case that both the poorest and the richest have difficulties to commit. The "average" users may then have to be more lenient towards both the richest and the poorest of their co-users.

The results are of relevance when analysing common-pool resource management, whether from a theoretical or a practical point of view. The interlinkage between resource management and inequality in the benefits from other economic activities have particularly important implications in the context of aid, land reforms and taxation. The results can also be used to improve the effectiveness of aid, by making it possible to target this to the groups where it would have a positive effect on common-pool resource management.

It is challenging to consider the possibility that free-riding by the rich may lead to a more efficient use of the common-pool resource than a higher maintenance level, and that alms-giving may be a way of increasing one's own consumption level, rather than an expression of altruism.

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