THE MANAGEMENT OF COMMON-POOL RESOURCES

THEORETICAL ESSAYS AND EMPIRICAL EVIDENCE

Ingela Ternström

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Contents

Introduction

This whole undertaking began with a feeling that it must be more difficult to cooperate in the use of a common resource for the really poor than for the not-so-poor. Walking around the country-side of Nepal, there was ample evidence that desperation can cause devastation. Eroding soil with anorectic trees where there used to be jungle. Landslides where there used to be pasture. However, there was also evidence of successful cooperative efforts. Common plots of land that had been fenced off to give the forest a chance to grow back, village ponds with plenty of fish.

These observations made me want to understand how the management of such resources was connected to poverty.

A large part of the world's population is dependent on this kind of local natural resources for their survival. If the resource is used in common by a limited group of people, for example herders grazing their animals on a common plot of land, villagers using a local forest for fetching fodder or collecting firewood or farmers joining forces to lead the water from a river to their fields, it is called a common-pool resource.

The people using a common-pool resource are dependent on each other. What one of them does with the resource affects what the others can do. For example, if the resource is an irrigation system, the amount of water one farmer takes affects how much is left to the others.

If the people using the resource can cooperate with each other, it can be used in a more sustainable manner. For example, if they agree to let only five goats each graze on a village common, all their goats may have enough to eat and the village common will be green, while if they cannot agree and all let as many goats graze as they can, the goats will be skinny and the village common barren. If the resource is an irrigation system, the farmers must decide how to allocate the water, who should clean and repair the canals and what action to take if someone does not follow these rules.

A large part of the people using common-pool resources are poor people living in developing countries. They often have limited access to markets and incomes that are so low that their health is dependent on how much they can get to eat.

This thesis is about cooperation among poor people using a common-pool resource.

The thesis consists of two theoretical and one empirical essay. The main theme of the theoretical essays is that the amount of food you already have determines how tempted you will be to break the rules of cooperation. In the empirical essay, I try to find out what really makes cooperation work.

In the first essay, I develop a theoretical model that takes into account that how highly you value an additional piece of the common-pool pie will depend on of how much use it is to you. I measure the use of an additional piece by looking at how your health is affected by it. If your belly is already full, an additional piece of the pie will not make much difference (it could even be bad for you). If you are seriously undernourished, your body will be so poor at transforming the pie into energy that it really does not make much difference here either. However, in between these extremes, that single piece of pie can actually make you feel a whole lot better.

I capture this by assuming utility to be S-shaped, and use game theory to find out how this affects cooperation. The main conclusion is that the chances for cooperation will be greater if the users of the common-pool resource are relatively well off than if they are very poor, but greatest of all in groups of users just managing to get the food they need. I also find that in most groups, a temporary decrease in the size of the common-pool pie will make it more difficult for the users to cooperate.

In the second essay, I take a step closer to reality by assuming that the users of the resource are not identical, at least not in terms of income level. This reveals that inequality makes cooperation less likely. I also find that when users are poor, the poorest will not cooperate, and when the users are richer, the richest will not cooperate. Alms-giving, an unequal sharing of the common-pool pie and even a certain amount of free-riding are ways of making cooperation possible, despite inequality.

In the third paper, I step fully into reality. Here, I take a look at what is really of importance for cooperation. Data from ten irrigation systems in Nepal are analysed and five of the systems are scrutinised in more detail. It turns out that the main insights from the first two essays were correct, but that it was not the whole truth. While those essays analysed whether it was possible for users to cooperate with each other, they must also agree on how to cooperate. The empirical analysis reveals that this is easier if there is a person leading them and if a large share of them belongs to the same ethnic group. Contrary to what may be expected, how many users there are and how old the irrigation system is does not seem to make any difference for cooperation.

Cooperation or Conflict in Common Pools*

Ingela Ternström[†]

Abstract

Many of the world's common pool resources are located in poor countries, where consumption levels may be sufficiently low to have an adverse effect on the users' health. Under these circumstances, an agent's utility function may be described as an S-shaped function of consumption. Using non-cooperative game theory, very poor groups of users are shown to have a lower probability of cooperative management of common pool resources, than groups with adequate consumption levels. However, the chances for cooperation are greatest for users that are only moderately poor. If there is a variation in resource productivity for this group, cooperation may break down in periods of low productivity. The theoretical results concur with empirical evidence of cooperation in common pool resources.

Keywords: Common-Pool Resources, Developing Countries, Dynamic Game, Irrigation, Natural Resources, Non-linear Utility.

JEL Classification: C72, O13, Q15, Q25

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†The Beijer Institute, The Royal Swedish Academy of Sciences, P.O. Box 50005, SE-104 05 Stockholm, Sweden. E-mail: Ingela.Ternstrom@beijer.kva.se

1 Introduction

A common-pool resource is a resource with a well-defined group of co-users. There is no individual ownership, but the group can exclude outsiders from the use of the resource. A large part of the third world's natural resources are managed as small local common-pool resources, for example irrigation systems, village forests, and fishing waters. There is a large literature on why and when we may expect cooperative management of such resources to be successful; what is lacking is an explicit consideration of the socioeconomic status of the people managing these resources.

Non-cooperative game theory has been used for analysing the common-pool resource problem for a long period of time. The infinitely repeated prisoner's dilemma is usually the preferred parable, since in a simple way, it captures how community incentives can keep short-run incentives to take more than one's share of the resource in check. This paper also uses non-cooperative game theory but includes the fact that in the third world, users of the resource are generally poor, and dependent on the resource for their survival or well-being. The paper explores how the users' incentives to cooperate are affected by their level of well-being under the following assumptions:

First, the marginal utility of consumption is highly dependent on the level of consumption, and there is thus a non-linear relationship between consumption and individual well-being. Second, credit markets are imperfect and therefore, do not compensate for the non-linearity of the utility function by smoothing consumption. Third, the state of the resource is controlled by exogenous factors such as weather conditions which, together with the users' actions, determine the level of output from the common-pool resource. The paper does not discuss the technology or dynamics of the resource.

Under these circumstances, how would we expect the users to act? On the one hand, an agent can gain more by cheating when the resource is large than when it is small. On the other hand, what is gained by cheating may not be worth as much when the resource is large.

This paper predicts a non-monotonic relationship between the size of the resource and the chances of cooperation within the group of users. Cooperation will be more difficult when the users are starving than in a well-fed group, but easiest of all in a group of people whose health would be seriously affected by a slight decrease in consumption. If we accept that the utility of an individual is closely related to her health, the model gives clear-cut implications: When the state of the resource is such that the users' body mass index[1] (BMI) is close to 20 if they cooperate, they will have the greatest chances of sustaining cooperation. From this point, both increases and decreases in the size of the resource will make cooperation more difficult.

Furthermore, changes in complementary income sources, as well as the in-

[1] The body mass index is a measurement of weight relative to height, BMI = weight/height^2.

troduction of markets for goods or capital, can make cooperation more difficult. When there is seasonal or stochastic variation in the exogenous factor determining the state of the resource, cooperation will be more difficult in periods with low resource-levels for most groups. However, the very poor will find the periods with high resource-levels to be the ones most prone to failed cooperation. I also find that cooperating part of the time can be a both possible and welfare improving alternative, when cooperating all the time is impossible. When I combine these results, the model is strongly supported by the empirical finding that in functioning common-pool resources, the relatively less productive period is the greatest challenge to cooperation.

Baland and Platteau (1996, Ch. 12) give a summary of the characteristics found to be important for successful cooperation in the empirical literature (mainly Ostrom (1990), Wade (1988) and McKean (1986)). One of these characteristics is that users should be highly dependent on the common-pool resource. There are also many empirical examples relating the breakdown of cooperation to resource scarcity. Regarding irrigation systems, Ostrom (1990) gives several examples of the connection between water scarcity and the temptation to cheat, and between bad times and actual rule-breaking.[2] Ostrom, Gardner and Walker (1994) state that "As the availability of water decreases, temptation increases for irrigators to break rules that limit water allocations".[3] Regarding irrigation systems in India, Baland and Platteau (1996) point to the high correlation between the degree of water scarcity and the level of activity of informal water users' organisations.[4] Wade (1987) argues that villagers confronting crisis conditions tend to behave opportunistically, and gives examples of such incidences.[5]

In the literature, there are also examples of very old common-pool resources that cease to function altogether with the disappearance of an outside income source. Baland and Platteau (1996, p. 266) tell the story of fishermen in Gahavälla, traditionally living off a combination of common-pool resource fishery- and wage-earnings from day labour. When the wage earnings ceased due to a reduction in the economic opportunities in agriculture, cooperation in fishery became more difficult to sustain and gradually, cooperation was replaced by violent competition for the fish; see also Jodha (1988) for a similar account. Berkes and Folke (1998) have given a number of other examples of the important links between resource availability and management regimes. Finally, the magnitude of the problem becomes evident when considering the degree of dependence on local resources in developing countries, as discussed in for example Dasgupta and

[2] See Ostrom (1990) pp. 69, 73 and 99 for examples.

[3] Ostrom, Gardner and Walker (1994) pp. 225-6.

[4] Baland and Platteau (1996) p. 210.

[5] Wade (1987) describes how desperation caused by a severe drought in an Indian village made people seriously consider breaking the rules of their common irrigation system. Wade interprets the reason for the behaviour in a slightly different way from what I do here. The breakdown of cooperation was avoided by increasing fines.

Mäler (1997).

On the theoretical side, the most closely related contribution is Spagnolo (1998), who studies the effect of concave utility on the outcome of repeated prisoner's dilemma games. Spagnolo also examines the role of markets for goods and capital under such circumstances. The present paper is also in some ways related to the problem of price wars in oligopolies, see for example Green and Porter (1984) and Rotemberg and Saloner (1986). While the former assume imperfect information, Rotemberg and Saloner make the same assumption as I do here, in that agents have full information regarding the state of the world, and come to similar conclusions. Their model predicts deviations in times of high demand, since that is when the gain from deviating is highest, while my model predicts deviations in bad periods, for exactly the same reason.

The paper proceeds as follows: The next section introduces the model and gives the optimal size of the resource. Section 3 introduces complementary income sources and markets for goods and capital to the model. In Section 4, I explore how variations in the size of the resource affects the chances of cooperation. In Section 5, I show that the chances of cooperation can be improved by introducing the possibility to cooperate in some periods only. Section 6 concludes.

2 The Model

Throughout the paper, my example will be that of farmers using an irrigation system to water their fields. The farmers are the agents in a dynamic prisoner's dilemma game over a common-pool resource, the irrigation system. To simplify the analysis, I assume that there are only two agents who are identical in all respects. The farmers' main source of food and income is the harvest from the fields that get water from the irrigation system. They have no access to markets for goods or credit and no storage facilities.[6] The amount of water in the irrigation system is given by the level of rainfall, which is perfectly observable. The benefit of the rain can be enhanced by the use of the irrigation system. The extent to which the use of the irrigation system benefits the farmers depends on whether they cooperate in its use. The farmers decide whether to cooperate by comparing the utility gained by taking different actions.

2.1 The Utility Function

The empirical examples given in the introduction indicate that there is a non-linearity in the cost-benefit ratio of deviating. There are at least three possible causes: The relationship between the amount of water and the size of the harvest may be non-linear, there may be a connection between nutrition and productivity that affects the harvest size in a non-linear fashion, and the utility gained from

[6] I extend the model to allow for markets for goods and credit, and storage in Section 3.2.

different levels of consumption may not be linear. If we have multiple sources of non-linearity, their combined effect depends on their relative location; they may either join forces or have a neutralising effect on each other.

Given that I am examining poor agents, I here choose to focus on the non-linearity in connection with the level of consumption. For poor people with mainly one source of food, the supply from this source will be crucial for their well-being. Figure 1 illustrates the S-shaped correlation between BMI and the probability of remaining in good health as presented by Dasgupta (1993, ch.14). Note that; *(i)* it takes a certain (above zero) BMI to have any chances at all of staying alive, *(ii)* the marginal health-benefit from food is increasing for low levels of food intake, and *(iii)* the marginal health-benefit from food is decreasing for high levels of food intake.[7]

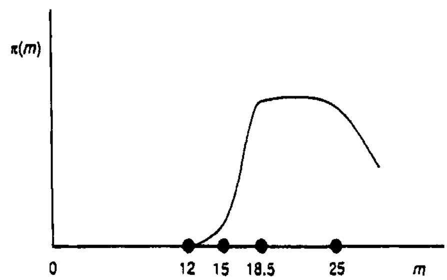

Figure 1: One minus the probability of health breakdown, $\pi(m)$, as a function of the body mass index, m. Source: Dasgupta (1993) p. 416.

The causes for the decreasing marginal health-benefit from food above certain levels are probably well known to everyone, but the increasing marginal health-benefit may need some explanation. The reason is that the human body uses energy to extract energy from food and if the food input is too low, there is not enough energy to make use of it in an efficient way. In this situation, a small decrease in the amount of food will not only decrease the amount of energy intake but also the amount of energy the body can extract from a given amount of food. In the western world, the problems are mainly related to the concave part of this relationship. However, among poor people in third world countries, the convex part is the more relevant one. According to FAO (1997), about 20 percent of the population in developing countries had inadequate access to food in 1990-92, implying a BMI of 18.5 or less.[8] These 20 percent will be measuring utility on the

[7]See also e.g. Weir (1995) for an estimate and a discussion of the effect of income on adult mortality.

[8]In the 20 countries with the lowest dietary energy supply level, on average 52 percent of the population were undernourished in 1990-92. In the second and third groups of countries, the percentage was 34 and 23, respectively (FAO, 1997). In low-income countries, on average 31 % of the children under the age of five suffered from malnutrition. Based on Table 6, World Development Report 1996.

non-concave part of the utility function. Assuming that it is the poorer rather than the richer parts of the population that depend on common-pool resources for their livelihood, the percentage becomes even higher.

The above figures make it abundantly clear that we must take the particularities of poor people into account when modelling common-pool resources in developing countries. For this purpose, we assume health to be an important component in utility. Thus, we can translate Dasgupta's food to health relationship into an S-shaped function of the utility from food, with one interval of non-decreasing positive marginal utility and one interval of non-increasing positive marginal utility from food.[9] As food in this model mainly comes from the crops grown on the farmers' fields, the implication is that the marginal utility of the harvest is largest when the BMI equivalent of the harvest is between 15 and 18.5. Based on the above discussion, I assume that the utility of consumption (or harvest) can be characterised as $U(C)$ with $U''(C) > 0$ for $C < \text{MMI}$, and $U''(C) < 0$ otherwise.[10] The inflexion point is referred to as MMI, the point of maximum marginal impact. C expresses the consumption level (or harvest size) in BMI-equivalents. Note that I implicitly assume that people will stop eating before food has a negative effect on their health. In the numerical examples, I use the following function, which is a good approximation of the relationship depicted in Figure 1, but with an asymptotically linear upper end.

$$U(C) = 100 \cdot \left\{1 + \frac{1}{1+C} \cdot \exp\left[-\gamma\left(C - \text{MMI}\right)\right]\right\}^{-1}, \tag{1}$$

where $\text{MMI} = 16.5$, and $\gamma = 1.25$.[11] The below figure shows the resulting utility function. I have assumed that the y-axis in Figure 1 is measured on a scale from 0-100 (for percentages), and utility is assumed to be measured on the same scale.

[9] See also Ravallion (1997) who uses a survival function that is concave above a consumption floor, below which there is simply not enough food to sustain the basic functions of the body.

[10] For readers who are not quite comfortable using an S-shaped utility function, note that I could instead use a linear utility function together with an S-shaped survival function. Let $P_A(\alpha\pi_{a_1,a_2})$ represent the probability of staying alive as a function of the size of the harvest. By letting $P_A(\alpha\pi_{a_1,a_2})\,\alpha\pi_{a_1,a_2} = U(\alpha\pi_{a_1,a_2})$, it is evident that the results will be identical.

[11] Note that for simplicity, the function is assumed to be symmetric around MMI. To make the relationship as similar as possible to that suggested by Dasgupta, I let $\text{MMI} = 16.5$, instead of the appropriate 18.5. This only slightly affects the illustrated results but should be kept in mind.

The x-axis shows the BMI-equivalent of consumption.

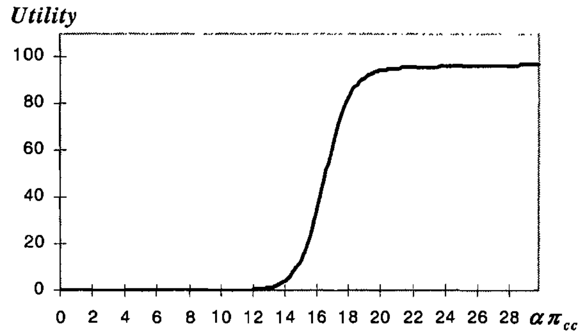

Figure 2: The utility function of equation (1).

2.2 Actions and Material Payoffs

In every period, each farmer $i \in \{1,2\}$ chooses an action $a_i \in \{c,d\}$, where c represents cooperation and d deviation. To focus the attention, the relative size of the harvests for different combinations of actions, π_{a_1,a_2}, is kept constant throughout the paper, which implies that as the level of rainfall changes, it is only the absolute productivity-level of the irrigation system that changes. The size of the harvests the farmers obtain when cooperating, relative to the size of their harvests when not cooperating, is unaffected.[12] What we then have is a common-pool resource game with variations in the absolute size of the payoffs (with the level of rainfall), but where the relative size remains the same. We can thus express farmer 1's consumption as $C = \alpha\pi_{a_1,a_2}$, with α being the amount of water. By assumption,

$$\pi_{d,c} > \pi_{c,c} > \pi_{d,d} > \pi_{c,d}. \tag{2}$$

Being a single deviator gives the largest harvest, and attempting to cooperate when the other farmer deviates results in the smallest harvest. I assume the sum of the harvests to be maximised under mutual cooperation, that is

$$2\pi_{c,c} > \pi_{d,c} + \pi_{c,d}. \tag{3}$$

Thus, the stage game will be a prisoner's dilemma with $\{d,d\}$ as the unique equilibrium.

[12] This is a simplification of reality. It may be more correct to assume that the harvest size is also an S-shaped function of water. This should, if anything, make the results more pronounced.

2.3 The Repeated Game

In the repeated game, I assume discrete time, t, and an infinite horizon. The size of the harvest in a certain time period determines the level of the farmers' utility during that same period. I assume that the farmers have identical discount factors, δ, which are independent of their consumption levels.[13]

A strategy is a prescription of what action to take at every stage, given the history of the game. We are interested in characterising a strategy generating the maximum amount of cooperation. From Abreu (1986, 1988), we know that in a repeated prisoner's dilemma game, a trigger strategy (where the agents choose the cooperative action in every period until, for the first time, they notice that someone has deviated, and thereafter shift to playing "deviate" forever) is optimal in this sense. If such trigger strategies cannot sustain cooperation, neither can any other strategies. Otherwise, cooperation is a possible equilibrium outcome. The discounted utility of behaving cooperatively, when all players do, will be

$$\sum_{t=0}^{\infty} \delta^t U\left(\alpha \pi_{c,c}\right), \tag{4}$$

and the discounted utility of deviating is

$$U\left(\alpha \pi_{d,c}\right) + \sum_{t=1}^{\infty} \delta^t U\left(\alpha \pi_{d,d}\right). \tag{5}$$

To test whether the trigger strategy can sustain cooperation, it suffices to check whether it will be beneficial for the agents to deviate from this strategy in a single period. Thus, for cooperation to be a subgame perfect equilibrium, expression (4) must be equal to or greater than expression (5).[14] Thus, cooperation can be sustained for all discount factors above the critical level,

$$\delta^*\left(\alpha\right) = \frac{U\left(\alpha \pi_{d,c}\right) - U\left(\alpha \pi_{c,c}\right)}{U\left(\alpha \pi_{d,c}\right) - U\left(\alpha \pi_{d,d}\right)}. \tag{6}$$

What I am interested in here is the effect on the critical discount factor of varying the amount of rainfall. From Spagnolo (1998), we know that with concave utility, the more concave are the agents' utility functions, the smaller will the critical discount factor at which a certain set of material payoffs can be supported as a subgame-perfect equilibrium outcome be. The intuition behind this result is that an agent with a strictly concave utility function has a lower marginal valuation of

[13] However, this implies assuming that the discount rate is not affected even when survival is threatened. Thus, we should be careful when interpreting the results for the lowest consumption levels, where the survival constraint will add to the difficulty of achieving cooperation by making the discount factor very small.

[14] Note that this is one among many equilibria, and that even though a cooperative equilibrium exists, it is not necessarily the one to be chosen.

the increased payoff gained by deviating and a higher marginal valuation of the decreased payoff when punished for it, than an agent with a linear utility function.[15] Applying this argument to my S-shaped model, the implication should be that with the same relative harvest sizes, the utility gained by deviating relative to the utility lost when punished for such an action will be larger when utility is convex than when it is concave. Thus, it should take a larger discount factor to deter deviations on the convex than on the concave segment. The following proposition verifies that the converse of Proposition 1 in Spagnolo (1998) also holds.

Proposition 1 *The critical discount factor is increasing in the convexity of the utility function.*

Proof. Solve for $U(\alpha\pi_{c,c})$ in (6) to get the following expression,

$$U(\alpha\pi_{c,c}) = \delta^* U(\alpha\pi_{d,d}) + (1-\delta^*)\, U(\alpha\pi_{d,c}). \tag{7}$$

This is equivalent to the definition of the certainty equivalent of a lottery with prizes $U(\alpha\pi_{d,d})$ and $U(\alpha\pi_{d,c})$, and probabilities δ^* and $1-\delta^*$. The risk premium, *RP,* of such a lottery is the difference between the expected value and the certainty equivalent,[16] that is,

$$RP = \delta^* U(\alpha\pi_{d,d}) + (1-\delta^*)\, U(\alpha\pi_{d,c}) - U(\alpha\pi_{c,c}). \tag{8}$$

Define the convexity measure $U''\left(\alpha\pi_{a_i,a_j}\right)/U'\left(\alpha\pi_{a_i,a_j}\right)$ (that is, the negative of the Arrow-Pratt measure of risk aversion). Since the risk-aversion and the concavity of the expected utility function are equivalent measures,[17] we know that as the concavity of the utility function increases, RP must increase. From (8), it is then obvious that δ^* must decrease when the concavity of the utility function increases, or equivalently, that the critical discount factor increases as the convexity of the utility function increases.

■

To understand what occurs in the intermediate segment, where $\text{MMI}/\pi_{d,c} < \alpha < \text{MMI}/\pi_{d,d}$, we return to equation (7). First, as the payoff from deviating increases above MMI, the growth rate of this payoff will be slowing down. To keep (7) satisfied, this must be countered by a decreasing critical discount factor. When α further increases, so that $\alpha\pi_{c,c} > \text{MMI}$, the cooperative payoff also starts

[15] Note, however, that while Spagnolo keeps the absolute material payoffs constant, I keep the relative size of the payoffs constant and thus, there is an increase in both the size and the spread of the material payoffs.

[16] See, for example, Kreps (1990) p. 84.

[17] See, for example, Varian (1992) p. 178.

to grow at a slower rate, and we get a counteracting force, which slows down the decrease in the critical discount factor. Figure 3 shows the resulting shape of the critical discount factor, with the x-axis showing the BMI-equivalent of the harvest size under cooperation.

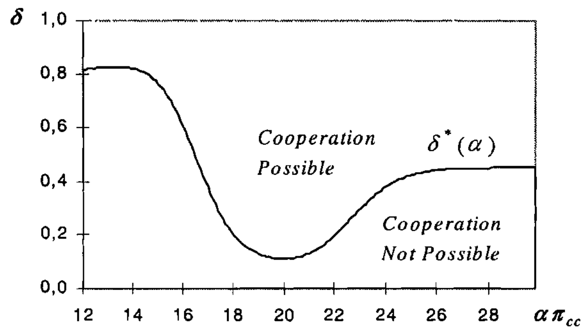

Figure 3: The critical discount factor when $\pi_{d,c} = 1.1\pi_{c,c}$ *and* $\pi_{d,d} = 0.9\pi_{c,c}$.

3 Empirical Implications

The results of the above analysis imply that if utility is linear, the amount of water available is irrelevant for the probability of cooperation. However, if utility is not linear, the curvature of the utility function is of crucial importance for the chances of cooperative management of the common-pool resource. With an S-shaped utility function, it is easier for a group to sustain cooperation if the amount of water is such that utility is measured on the concave segment of the utility function than on the convex segment. The most discouraging result is, of course, that the groups with the greatest need to increase the harvest size above the cooperative level are also the ones with the greatest risk of instead having it reduced.

Furthermore, increasing the difference between relative payoffs makes cooperation easier at intermediate and large resource levels but increases the critical discount factor when the resource is small, as illustrated below.

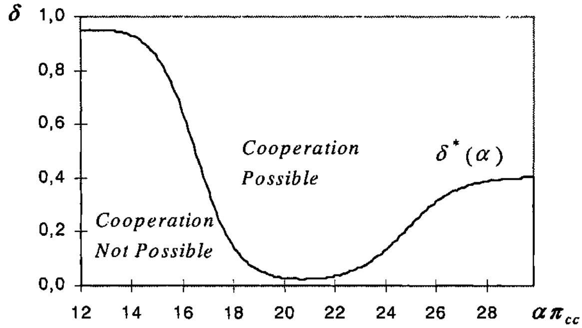

Figure 4: The critical discount factor with larger differences between relative payoffs, $\pi_{d,c} = 1.2\pi_{c,c}$ *and* $\pi_{d,d} = 0.8\pi_{c,c}$.

Given that we accept the assumption of utility being dependent on health, the model gives clear-cut numerical results. From the graphical presentations in Figures 3 and 4, it is obvious that a BMI of around 20 when cooperating provides the best chances of successful cooperation. If the resource is smaller, a smaller supply makes cooperation more difficult. Comparing these results with the above discussion on the average BMI in poor countries, we can conclude that it is the poor but not starving who have the best chances of cooperating, and that this group constitutes a substantial part of the population in poor countries.

3.1 Additional Income Sources

With a slight change in the model, we can analyse a case where the agents have an additional source of income, for example a wage from day labour. The consumption level will now be a sum of the income from the two sources, $C = \alpha + \pi_{a_1,a_2}$. Let the additional income source be the one depending on the exogenous variable α (which need no longer be rainfall), and let the size of the harvest depend only on the cooperative success of the farmers. The result is to give α an additive, rather than a multiplicative, effect.[18] By performing the same analysis as above, we can analyse how different sizes of the complementary income affect the cooperative efforts of the farmers. The critical discount factor will now be as follows, with the subscript *add* for additive,

$$\delta^*_{add}(\alpha) = \frac{U(\alpha + \pi_{d,c}) - U(\alpha + \pi_{c,c})}{U(\alpha + \pi_{d,c}) - U(\alpha + \pi_{d,d})}. \tag{9}$$

The figure below shows that if, instead of letting the level of rainfall differ, we give the group of farmers a complementary source of food or income and let this

[18]This also implies constant absolute, instead of relative, payoffs sizes.

differ, we obtain very similar results, but with a different interpretation.

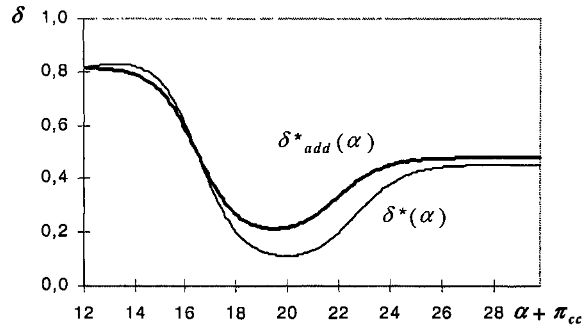

Figure 5: The critical discount factor with a complementary income source when the return from the common-pool resource is too small to survive on; $\pi_{c,c} = 12$, $\pi_{d,c} = 1.1\pi_{c,c}$ *and* $\pi_{d,d} = 0.9\pi_{c,c}$.

The implication is that the success of the cooperative management of a common-pool resource also depends on the size of the complementary income sources of the users. If the complementary income is such that it minimises the critical discount factor, the system is sensitive to changes in the size of the complementary income in either direction.

By varying the size of the material payoffs relative to the size of the complementary income, we can study the effects of different degrees of dependence on the common resource. As the payoffs from using the resource become a smaller part in total consumption, the function of the critical discount factor becomes flatter. This implies that there is a decrease in the sensitivity to changes in the additional source of income, but also that it becomes more difficult to cooperate at intermediate income levels.

Baland and Platteau's description of what happened to the fishermen in Gahavälla (see the introduction) is a good example of a change in an additional income source. The common-pool fishery had developed and improved over a long period of time, from which we may suspect that the system was operating on a scale where cooperation was easily sustained. The disappearance of their complementary source of income implied a left-ward move along the utility curve and an increased critical discount factor. Consideration for these kinds of effects should be given when choosing the location for aid projects, both when the project itself requires cooperative management, and when there are pre-existing common-pool resources.

3.2 Storing, Saving and Selling

What would happen if we were to introduce the possibility of saving part of the harvest until future periods? In theory, users with a convex utility would increase their total utility by making their consumption as uneven as possible. Thus, they could gain a very high marginal utility in one period at the cost of an only slightly reduced utility in other periods. It is, however, difficult to imagine that a person close to dying from starvation would voluntarily relinquish any of his consumption today for use in a future period, since that future period may never come. In such a situation, the discount rate is likely to be too high to make savings a feasible alternative. Thus, I shall refrain from using my model to analyse this case. As far as credits are concerned, I shall simply assume that users on the convex segment are ineligible for loans, and thus will not be able to make use of credit markets, even if they want to.

Thus, I here focus on the concave part of the utility function. With concave utility, being able to reallocate the consumption of some of the additional harvest gained when deviating to one punishment period or more will increase the marginal utility of the reallocated amount and thus, the total benefit from deviating. However, unless the storage methods are perfect, there will be a loss connected with transferring the harvest in time. The smaller is this loss, the more of an obstacle to cooperation storage will be. Assuming that a share $s \in [0, 1]$ of the difference between the size of the harvest when deviating and when being punished is saved for one period, and that a fraction $r \in [0, 1]$ of the saved harvest remains after one year of storage, we can write the condition for storage facilities to be harmful to cooperation as

$$\begin{aligned} &U\left[\alpha\pi_{d,c} - (1-s)\left(\alpha\pi_{d,c} - \alpha\pi_{d,d}\right)\right] + \delta U\left[\alpha\pi_{d,d} + rs\left(\alpha\pi_{d,c} - \alpha\pi_{d,d}\right)\right] \\ &> U\left(\alpha\pi_{d,c}\right) + \delta U\left(\alpha\pi_{d,d}\right). \end{aligned} \tag{10}$$

The larger is r and the more concave is the utility function (that is, the larger is the difference in marginal utilities), the larger is the left-hand side of equation (10), and the more of a threat will storage be to cooperation.

If we introduce credit markets on top of a perfect storage method, thus adding the possibility of earning interest on the saved amount, the effect is the same as if the fraction remaining after storage were larger than one ($r > 1$). Furthermore, credit institutions would make it possible to spread the gains from deviating over more than two periods, thereby further increasing the marginal utility of deviating.[19]

The effect of introducing goods markets may be illustrated as an increase in the marginal benefit from deviating, since there is a market on which the additional harvest gained by deviating can be exchanged for other goods with a higher marginal utility. This implies making the concave part of the utility function steeper, that is, making utility move more quickly towards its maximum.[20] In the below figure (where we have increased γ in equation (1) to 1.50

[19]For a more thorough analysis see, for example, Spagnolo (1998).

[20]Kranton (1996) and Spagnolo (1998) provide different approaches and formal analyses of the effect of market access on reciprocal-exchange and cooperation, respectively.

for $\alpha\pi_{a_1,a_2} \geq$ MMI), we see that this makes cooperation more difficult at the upper end of the utility function. Jodha (1988) suggests that the introduction of a nearby marketplace is harmful to the cooperative management of a common-pool resource, since it reduces the social cohesion, thus making it more difficult to maintain the social norms regulating the use of the common resource. Another explanation could thus be the possibility of changing the composition of consumption and thereby get a higher marginal utility from deviating.[21]

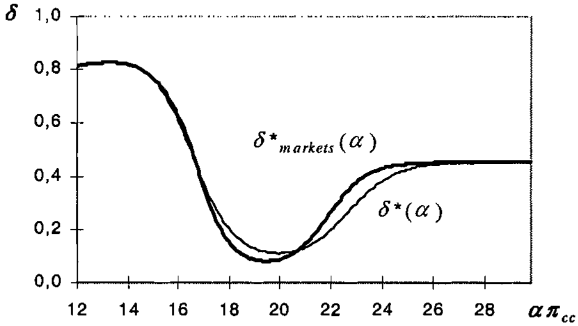

Figure 6: The critical discount factor with access to markets, when $\pi_{d,c} = 1.1\pi_{c,c}$, $\pi_{d,d} = 0.9\pi_{c,c}$.

4 Variations in the State of the Resource

In this section, I extend the base-line model to analyse the effect on cooperation of variations in the amount of rainfall. I here focus on stochastic variations, while the analysis of seasonal variations is referred to in Appendix A. Note that this is no longer a repeated game, since there is variation in the state of the resource. Thus, the trigger strategy used so far may no longer be the optimal strategy. The extension in Section 5 shows a strategy that may improve the outcome, however.

4.1 Stochastic Variations

Suppose that weather is variable and somewhat unpredictable. The farmers know the possible levels of rainfall and their likelihood, but do not know what the actual level will be until each period begins. We thus continue to assume that farmers have full information about the level of rainfall in the present period, but now also assume future levels of rainfall to be stochastic. To simplify the analysis,

[21]Since γ is constant, the figure also shows a change in the critical discount factor at consumption levels below the inflexion point, although this is not what I intended to illustrate. Ideally, the effect should be modelled with different levels of γ for the convex and concave parts of the utility function.

we assume *i.i.d.* shocks and only two possible levels of rainfall, wet (α_w) or dry (α_d), with $\alpha_w \geq \alpha_d$ always.[22]

In each period of time, we let the probability of the high level of rainfall be p_w. Define the possible levels of rainfall in future periods as $\alpha_\tau \in \{\alpha_w, \alpha_d\}$, where $\tau \in \{t > 0\}$. We write the expected utility[23] from a certain combination of actions in any future period as

$$E_\tau \left[U \left(\alpha_\tau \pi_{a_1,a_2} \right) \right] = p_w U \left(\alpha_w \pi_{a_1,a_2} \right) + \left(1 - p_w \right) U \left(\alpha_d \pi_{a_1,a_2} \right). \tag{11}$$

To find the critical discount factor of a wet period, $\delta^*_{stoch}(\alpha_w)$, we set the discounted expected utility from cooperating equal to the discounted expected utility from deviating,

$$U \left(\alpha_w \pi_{c,c} \right) + \sum_{t=1}^{\infty} \delta^t E_\tau \left[U \left(\alpha_\tau \pi_{c,c} \right) \right] = U \left(\alpha_w \pi_{d,c} \right) + \sum_{t=1}^{\infty} \delta^t E_\tau \left[U \left(\alpha_\tau \pi_{d,d} \right) \right], \tag{12}$$

and solve for the critical discount factor,

$$\delta^*_{stoch}(\alpha_w) = \frac{U(\alpha_w \pi_{d,c}) - U(\alpha_w \pi_{c,c})}{U(\alpha_w \pi_{d,c}) - U(\alpha_w \pi_{c,c}) + E_\tau \left[U(\alpha_\tau \pi_{c,c}) \right] - E_\tau \left[U(\alpha_\tau \pi_{d,d}) \right]}. \tag{13}$$

The critical discount factor of a dry period is, correspondingly,

$$\delta^*_{stoch}(\alpha_d) = \frac{U(\alpha_d \pi_{d,c}) - U(\alpha_d \pi_{c,c})}{U(\alpha_d \pi_{d,c}) - U(\alpha_d \pi_{c,c}) + E_\tau \left[U(\alpha_\tau \pi_{c,c}) \right] - E_\tau \left[U(\alpha_\tau \pi_{d,d}) \right]}. \tag{14}$$

The sum in the numerator represents the benefit from deviating, while the sum of the two expected utilities in the denominator represents the expected punishment. Since the expected punishment is the same for both outcomes, it will take a higher discount factor to sustain cooperation in the outcome giving the largest benefit from deviating. Thus, we can state the following:

Proposition 2 *When rainfall is stochastic, cooperation is easier in the wet than in the dry period, if and only if* $U(\alpha_w \pi_{d,c}) - U(\alpha_w \pi_{c,c}) < U(\alpha_d \pi_{d,c}) - U(\alpha_d \pi_{c,c})$.

Proof. Assume that $\delta^*_{stoch}(\alpha_w) < \delta^*_{stoch}(\alpha_d)$. Substituting from equations (13) and (14) and simplifying yields

$$U(\alpha_w \pi_{d,c}) - U(\alpha_w \pi_{c,c}) < U(\alpha_d \pi_{d,c}) - U(\alpha_d \pi_{c,c}). \tag{15}$$

■

[22]In reality, there will be many possible levels of rainfall, not just two as assumed here. This should not have any major effect on the analysis, as the only difference in the equation for the critical discount factor will be that the expected loss from deviating consists of more terms.

[23]Note that I assume the von Neumann-Morgenstern expected utility function to be identical to the S-shaped utility function used so far.

On the one hand, the size-effect of more rain in the wet period will always work in the direction of making cooperation more difficult. On the other hand, the non-linearity of the utility function creates a utility-effect that may work in the other direction. A necessary condition for the dry period being the more difficult for cooperation is that the gain from deviating falls on a steeper segment of the utility function in the dry than in the wet period. Thus, as Figure 7 shows, it is mainly with intermediate levels of rainfall in the dry period that it will be significantly more difficult to cooperate in the drier year.[24]

Combining this result with the main result of the analysis in Section 3, we can conclude that when the chances in cooperation are the highest, the relatively poorer period is the greatest challenge to cooperation. This is exactly what was reported in the empirical studies referred to in the introduction. In functioning common-pool resources, deviations mainly occur in the less productive period.

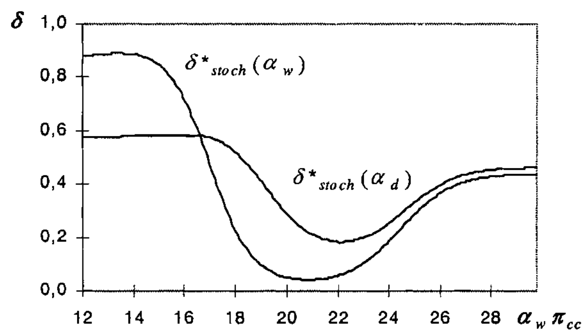

Figure 7: Stochastic variations in the amount of rainfall when $\pi_{d,c} = 1.1\pi_{c,c}$*,* $\pi_{d,d} = 0.9\pi_{c,c}$*,* $\alpha_d = 0.9\alpha_w$*, and* $p_w = 0.5$*. Note that the x-axis gives the cooperative payoff in the wet period.*

Let us look at some implications of these results. From Figure 7, it is obvious that there is one point at which cooperation is particularly sensitive to changes in the levels of rainfall. At $\alpha_w\pi_{c,c} \approx$ MMI, a very slight change in α can cause a regime shift in terms of in which period it is easier to cooperate.

A change in the difference between the possible levels of rainfall can have similar drastic effects. According to the IPCC,[25] a possible effect of global warming is an increased variability in the climate. A simple numerical example illustrates how this could affect the management of common-pool resources. In Figure 8,

[24]The main difference between this case and that with seasonal variations lies in the calculation of the sizes of future harvests, where the probability in the stochastic case, and the timing in the seasonal case, affect the outcome. When I let the relative probability of the levels of rainfall in the stochastic case equal the relative length of the seasons in the seasonal case, the results are very similar.

[25]See e.g. Houghton, Callander and Varney (1992).

we have increased the difference between the two possible levels of rainfall by letting $\alpha_d = 0.7\alpha_w$. When $\alpha_w\pi_{c,c}$= 20 in Figure 7 and $\alpha_w\pi_{c,c}$= 22.35 in Figure 8, I have the same average amount of rainfall (and thus, the same average consumption level) in the two cases. Comparing the two figures, I find quite a dramatic increase in the critical discount factor of the dry period. Unless the farmers' discount factor is very high, this will lead to a collapse of cooperation. If, at the same time, there is a change in the average amount of rainfall, this will also alter the critical discount factors. Thus, global warming may have a hidden side-effect, which has the potential of causing substantial costs to society, both in terms of conflicts and a less efficient use of local natural resources.

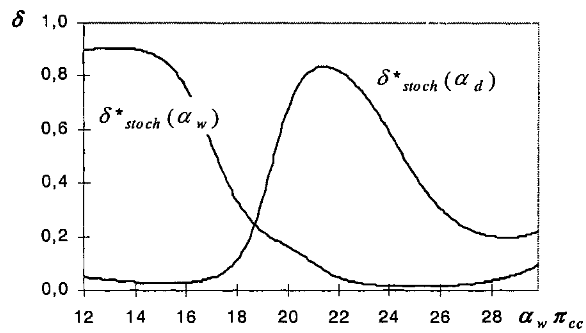

Figure 8: The effects of an increased variability in rainfall, $\pi_{d,c} = 1.1\pi_{c,c}$, $\pi_{d,d} = 0.9\pi_{c,c}$, $\alpha_d = 0.7\alpha_w$, *and* $p_w = 0.5$.

5 Partial Cooperation

Now, if farmers know that cooperation will fail because it cannot be sustained in some periods, is there any alternative strategy which could improve their situation? There are empirical examples of common-pool resources where the users forgive fellow users for breaking the rules, if this is due to bad times. In their study of land relations in Rwanda, André and Platteau (1998) found that there was a more lenient attitude towards *voleurs par faim* (thieves out of hunger), than towards *voleurs par défaut* (vicious thieves). McKean (1986) describes how rule-breaking in a Japanese village forest was ignored if it took place in particularly bad years. I shall thus examine whether the chances of cooperation can be increased by a more forgiving attitude.[26]

First of all, define easy periods as periods when the critical discount factor, δ^*, is not larger than the farmers' discount factor, δ, and difficult periods as those when it is. Thus, cooperation is possible in easy periods only. Let the variable θ

[26] As above, we will here focus on the stochastic case, and refer the analysis of the seasonal case to Appendix B.

describe whether cooperation could have been credibly sustained in period t:

$$\theta_t = \begin{cases} 1 & if \quad \delta \geq \delta_t^*; \\ 0 & if \quad \delta < \delta_t^*. \end{cases} \tag{16}$$

Let the actions taken by each of the farmers in period t be represented by

$$a_t = \{a_{1,t},\ a_{2,t}\}. \tag{17}$$

We can now describe the history of the game at date T,

$$h_T = \{a_t,\ \theta_t\}_{t=0}^{T-1}. \tag{18}$$

The extended trigger strategy will prescribe cooperation in easy periods, $\theta_t = 1$, until history for the first time contains any time period when it would have been possible to cooperate, but some farmer did not, that is, until

$$h_T = \{a_{i,t} = d,\ \theta_t = 1\} \qquad some\, t < T,\ some\, i, \tag{19}$$

and then deviate for ever. Deviations in difficult periods, $\theta_t = 0$, will be forgiven and are not punished, which means that we must adjust the expected cost of deviating to the removal of the punishment in the difficult period.[27] Substituting from equation (11), if farmers are allowed to ignore deviations in dry years, the two expected utilities in the denominator of equation (13) become

$$\begin{aligned} & E_\tau\left[U\left(\alpha_\tau \pi_{c,c}\right)\right] - E_\tau\left[U\left(\alpha_\tau \pi_{d,d}\right)\right] \\ & = p_w U\left(\alpha_w \pi_{c,c}\right) + \left(1 - p_w\right) U\left(\alpha_d \pi_{d,d}\right) \\ & - p_w U\left(\alpha_w \pi_{d,d}\right) + \left(1 - p_w\right) U\left(\alpha_d \pi_{d,d}\right) \\ & = p_w\left[U\left(\alpha_w \pi_{c,c}\right) - U\left(\alpha_w \pi_{d,d}\right)\right]. \end{aligned} \tag{20}$$

The equation giving the critical discount factor changes accordingly. If the wet period is the easy period, we have (with superscript x for extended)

$$\delta_{stoch}^x\left(\alpha_w\right) = \frac{U\left(\alpha_w \pi_{d,c}\right) - U\left(\alpha_w \pi_{c,c}\right)}{U\left(\alpha_w \pi_{d,c}\right) - U\left(\alpha_w \pi_{c,c}\right) + p_w\left[U\left(\alpha_w \pi_{c,c}\right) - U\left(\alpha_w \pi_{d,d}\right)\right]}, \tag{21}$$

and the equivalent for the dry period when that is the easy period. I want to compare the lower of these with

$$\delta_{max}^* = max\left\{\delta_{stoch}^*\left(\alpha_d\right), \delta_{stoch}^*\left(\alpha_d\right)\right\}. \tag{22}$$

When δ_{stoch}^x is below δ_{max}^*, as for intermediate values of $\alpha_w \pi_{c,c}$ in Figure 9, the extended trigger strategy can improve the chances of cooperation. If the farmers'

[27]Note that we here assume a full reversal to non-cooperative behaviour in the difficult periods. Another, and perhaps more realistic, assumption would be that partial deviations are allowed. We also assume that agents can effortlessly return to cooperation after the difficult period.

discount factor is between these two, they will be able to sustain cooperation by following the extended trigger strategy, although cooperation was not possible without forgiveness.

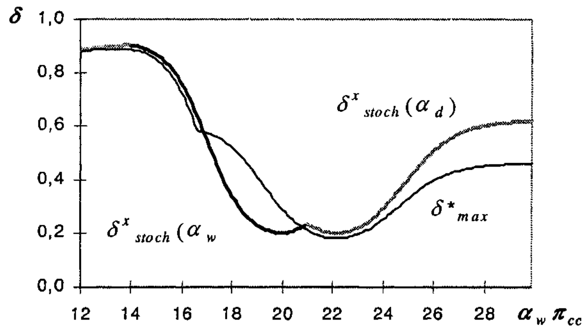

Figure 9: The effect of forgiveness with stochastic variations in the level of rainfall, $\pi_{d,c} = 1.1\pi_{c,c}$, $\pi_{d,d} = 0.9\pi_{c,c}$, $\alpha_d = 0.9\alpha_w$, *and* $p_w = 0.5$.

Note the similarity with Rotemberg and Saloner's (1986) result that price wars in oligopolies should be observed in periods of high demand. The intuition behind their result is that deviation gives a higher gain when demand is high. To avoid a total breakdown of cooperation, the oligopoly allows for a lower price in such periods, in other words deviations are forgiven to a certain extent. In my case, a total breakdown of cooperation can also be avoided by forgiving deviations in periods when the gain from deviating is particularly high. The difference is that I measure the gain in terms of utility instead of material payoffs, and that I do not allow for partial deviations.

6 Final Remarks

In this paper, I have shown that when utility is non-linear, the consumption level of the users of a local common-pool resource affects the chances of cooperative management of the resource. The results correspond well with empirical studies of common-pool resource management. In particular, we saw that groups of users with an intermediate consumption level, here meaning poor but not starving, will have the best chances of cooperative management. If there is variation in the size of the resource, the relatively worse period will constitute the largest threat to cooperation for this group.

The model builds on some assumptions that may seem rather restrictive. I confine myself to groups of users whose utility is closely related to their state of health which, in turn, is closely related to their consumption level. Furthermore, I assume that they have no access to goods or credit markets. Nevertheless, when we place the local common-pool resources in one of the least developed countries, neither of these assumptions is at all implausible.

Throughout the paper, I have implicitly assumed that there is no time dependency, neither in the users' health nor in their use of the resource. Introducing time dependence, for example in the form of a stock-variable for health, or by letting the farmers' actions in one period have an effect on the productivity of the resource in future periods, would naturally affect the results. Even more restrictive is perhaps the assumption that monitoring is perfect and costless, and that the only punishment is to revert to a total lack of cooperation. Judging from the empirical studies reported by, for example, Ostrom (1990), assuming that monitoring is costly, imperfect and of varying intensity, and that there are other forms of punishment of varying severity, would be more realistic. Finally, I have assumed the discount rate to be independent of the consumption level. If it were not, cooperation would become even more difficult at the lowest consumption levels, but may become easier at the highest consumption levels.

It would be interesting to extend the model to more than two users, so that the larger is the amount of farmers sharing the water of the irrigation system, the less water there is for each of them. The harvest on each farmer's field would then partly depend on how the irrigation system is managed, partly on the annual rainfall and also partly on how many farmers share the water. Herein lies a possibility for an endogenous size of the user group decided by, for example, in- and out-migration of users to accommodate for seasonal or stochastic changes in the weather. Exogenous changes in the number of users due to, for example, population growth within or outside the group, would have similar effects as the changes in the size of the resource that I have discussed in this paper.

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Appendix A: Seasonal Variations

We here analyse seasonal variations in the amount of water in the irrigation system. Many areas have one rainy and one dry season. As seasons vary, so does the level of rainfall and, by now, we know enough to expect this to have repercussions on the farmers' ability to cooperate. Once more, I assume that there are only two possible outcomes, wet and dry, but here, I let every other period be wet and every other period dry. Thus, there is the same variability as with stochastic variations, but none of the uncertainty of that case. This implies that it is the timing rather than the probabilities of the two possible outcomes that determines the expected loss from deviating. Thus, there will be a difference between the two seasons' costs of deviating, affecting their critical discount factors.

Assume that each farming year consists of two seasons of equal length, with α_w and α_d denoting the levels of rainfall in the wet and dry seasons, with $\alpha_w \geq \alpha_d$. In a wet season, the discounted utility of cooperating will be

$$\sum_{t=0}^{\infty} \delta^{2t} \left[U\left(\alpha_w \pi_{c,c}\right) + \delta U\left(\alpha_d \pi_{c,c}\right) \right], \tag{23}$$

and the discounted utility of deviating

$$U\left(\alpha_w \pi_{d,c}\right) - U\left(\alpha_w \pi_{d,d}\right) + \sum_{t=0}^{\infty} \delta^{2t} \left[U\left(\alpha_w \pi_{d,d}\right) + \delta U\left(\alpha_d \pi_{d,d}\right) \right]. \tag{24}$$

To avoid deviation, it must be true that

$$\begin{aligned} &\delta^2 \left[U\left(\alpha_w \pi_{d,c}\right) - U\left(\alpha_w \pi_{d,d}\right) \right] \\ &+\delta \left[U\left(\alpha_d \pi_{c,c}\right) - \delta U\left(\alpha_d \pi_{d,d}\right) \right] \\ &+U\left(\alpha_w \pi_{c,c}\right) - U\left(\alpha_w \pi_{d,c}\right) \\ &\geq 0. \end{aligned} \tag{25}$$

We can express the critical discount factor of a wet season[28] as

$$\begin{aligned} \delta^*_{seas}\left(\alpha_w\right) = &\frac{U\left(\alpha_d \pi_{c,c}\right) - \delta U\left(\alpha_d \pi_{d,d}\right)}{2\left(U\left(\alpha_w \pi_{d,c}\right) - U\left(\alpha_w \pi_{d,d}\right)\right)} + \\ &\left\{ \left[\frac{U\left(\alpha_d \pi_{c,c}\right) - \delta U\left(\alpha_d \pi_{d,d}\right)}{2\left(U\left(\alpha_w \pi_{d,c}\right) - U\left(\alpha_w \pi_{d,d}\right)\right)} \right]^2 \right. \\ &\left. + \frac{U\left(\alpha_w \pi_{d,c}\right) - U\left(\alpha_w \pi_{c,c}\right)}{U\left(\alpha_w \pi_{d,c}\right) - U\left(\alpha_w \pi_{d,d}\right)} \right\}^{1/2} \end{aligned} \tag{26}$$

[28]Note that we disregard the negative root.

and the critical discount factor of a dry season as

$$\delta^*_{seas}(\alpha_d) = -\frac{U(\alpha_w\pi_{c,c}) - \delta U(\alpha_w\pi_{d,d})}{2(U(\alpha_d\pi_{d,c}) - U(\alpha_d\pi_{d,d}))} + \left\{\left[\frac{U(\alpha_w\pi_{c,c}) - \delta U(\alpha_w\pi_{d,d})}{2(U(\alpha_d\pi_{d,c}) - U(\alpha_d\pi_{d,d}))}\right]^2 + \frac{U(\alpha_d\pi_{d,c}) - U(\alpha_d\pi_{c,c})}{U(\alpha_d\pi_{d,c}) - U(\alpha_d\pi_{d,d})}\right\}^{1/2}. \tag{27}$$

A comparison of Figures 7 and 10 shows that despite these rather messy expressions, the result is very similar to the case with stochastic variations and an equal probability of the two outcomes. The slight difference is caused by the difference in the expected cost of deviating.

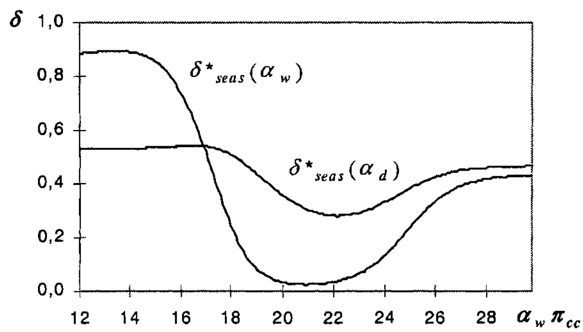

Figure 10: Seasonal variations in the level of rainfall when $\pi_{d,c} = 1.1\pi_{c,c}$, $\pi_{d,d} = 0.9\pi_{c,c}$, and $\alpha_d = 0.9\alpha_w$.

Appendix B: Partial Cooperation with Seasonal Variations

In this appendix, I confirm that a forgiving attitude can increase the chances of cooperation in the seasonal as well as in the stochastic case. When the easy season is a wet season, the extended trigger strategy results in the following discounted utility from cooperating,

$$\sum_{t=0}^{\infty} \delta^{2t} \left[U\left(\alpha_w \pi_{c,c}\right) + \delta U\left(\alpha_d \pi_{d,d}\right)\right], \tag{28}$$

and from deviating

$$U\left(\alpha_w \pi_{d,c}\right) - U\left(\alpha_d \pi_{d,d}\right) + \sum_{t=0}^{\infty} \delta^{2t} \left[U\left(\alpha_w \pi_{d,d}\right) + \delta U\left(\alpha_d \pi_{d,d}\right)\right]. \tag{29}$$

From this, I get the critical discount factor,

$$\delta_{seas}^{x}\left(\alpha_w\right) = \frac{U\left(\alpha_w \pi_{d,c}\right) - U\left(\alpha_w \pi_{c,c}\right)}{U\left(\alpha_w \pi_{d,c}\right) - U\left(\alpha_w \pi_{d,d}\right)}, \tag{30}$$

that is, the square root of the critical discount factor for the same amount of rainfall in the base-line case. Figure 11 shows that, as in the stochastic case, there is an intermediate size of the resource where cooperation will be facilitated if farmers are more forgiving.

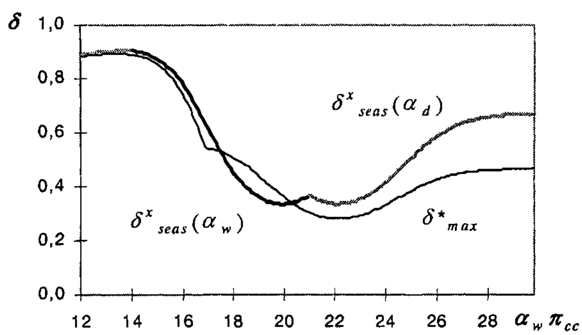

Figure 11: The effect of forgiveness with seasonal variations in the level of rainfall, when $\pi_{d,c} = 1.1\pi_{c,c}$, $\pi_{d,d} = 0.9\pi_{c,c}$, $\alpha_d = 0.9\alpha_w$.

Income Inequality and Cooperation in Common Pools*

Ingela Ternström†

Abstract

There is empirical evidence of income inequality having a negative effect on common-pool resource management, and contributing to an unequal sharing of the resource. I show that if utility is assumed to be S-shaped, non-cooperative game theory can be used to explain this 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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†The Beijer Institute, The Royal Swedish Academy of Sciences, P.O. Box 50005, SE-104 05 Stockholm, Sweden. E-mail: Ingela.Ternstrom@beijer.kva.se

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. Although many studies find that richer users getting the larger share of the gains from the cooperative efforts,[1] Wade (1988), found that the richer users were sometimes those contributing more. André and Platteau (1998) give evidence from Rwanda that the poor 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]

The purpose of this paper is to develop a better theoretical explanation for the empirical evidence. The theory presented here assumes that agents are identical in all aspects other than their consumption level. Thus, 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 lack access to markets, there is a strong connection between income 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,

[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).

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

it is arguable that utility is an S-shaped function of income.

The management of the common-pool resource is analysed as a repeated prisoners' dilemma game, and inequality among agents is shown to lead to different critical discount factors. In other words, 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 user 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, 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. If the richer user cannot commit, he could be made somewhat poorer - or, assuming there is no one around with such power, he could be given a larger share of the gains from cooperation. 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 distribution of the gains from cooperation, as a way of sweetening the deal for the rich. 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 (2001), who analyses the effects of S-shaped utility on cooperative management of common pools. Baland and Platteau (1999, 1998 and

James (1994).

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.[5]

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 external sources. Agent R gets a higher income from external sources than agent P, that is $K_{\mathrm{R}} > K_{\mathrm{P}}$. 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 combination of both. 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.[6]

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,

[5] 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 the literature on private provision of public goods; see, for example, Warr (1983) and Bergstrom et.al. (1986).

[6] When multiplicative, the external income increases the productivity of the common pool resource by a factor $e(K_i)$, 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.

known to generate the maximum amount of cooperation in ordinary repeated prisoners' dilemma games,[7] 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. 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

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

From this expression, we derive the minimum discount factor at which agent i can 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) 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. That is, the utilities on the right-hand side of Equation (4) are smaller, the more concave is the utility function. Ternström (2001) extends this analysis to characterise the scope for cooperation between identical individuals

[7] See Abreu (1986, 1988).

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 (2001). Figure 1 depicts a utility function whose shape closely mirrors the relationship between health and BMI suggested by Dasgupta (1993).[8]

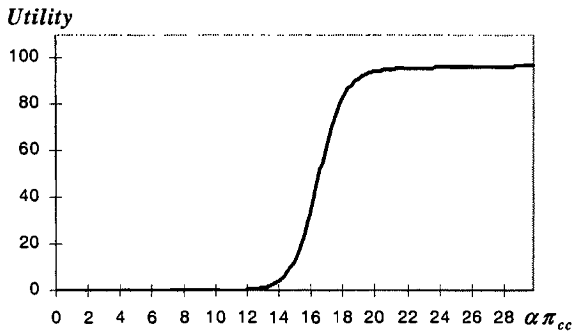

Figure 1. Utility as an S-shaped Function of Income. Source Ternström (2002).

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 20, where the function is maximally concave.[9] The function then increases in convexity once more as the utility function becomes asymptotically linear. Figure 2

[8]See Ternström (2001) for details.

[9]The specification of the function is an approximation of the relationship suggested by Dasgupta. There may be some discrepancy between the values as given by Dasgupta and the values indicated in the figure here. The figures are to be seen as an illustration only.

shows the corresponding critical discount factor.[10]

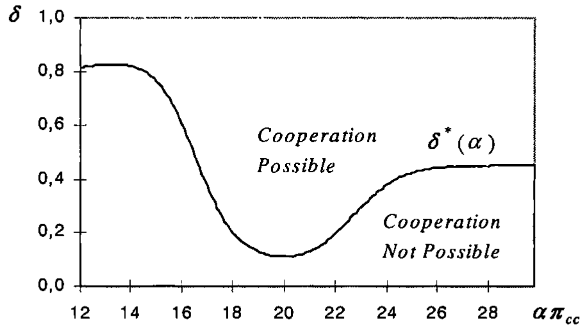

Figure 2. The Critical Discount Factor when Utility is S-shaped. Source Ternström (2002).

The two figures illustrate that the critical discount factor is higher, the more convex is the utility function.[11] Since cooperation requires the discount factor to be greater than the largest critical discount factor, 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. If we define I as total income and let $\widehat{I}$ be the income level where $U(I)$ is maximally convex, the above question can be answered as follows:

Proposition 1 *If $\widehat{I} < I_{\text{P}} < I_{\text{R}}$, then increased inequality makes cooperation more difficult. Otherwise, increased inequality may facilitate cooperation.*

The result follows from Proposition 1 in Spagnolo (1998) and is easiest understood by considering Figure 2. To the right of its maximum (corresponding to $\widehat{I}$), the critical discount factor is U-shaped. On the

[10]The relative payoffs are fixed to $\pi_{d,c} = 1.1\pi_{c,c}$ *and* $\pi_{d,d} = 0.9\pi_{c,c}$ for the different actions. The growth in consumption is caused by a change in the size of the resource, α.

[11]The minimum and maximum points of the critical discount factor may not be located exactly at the points of minimum and maximum convexity of the utility function, as the relative size of the material payoffs will also have an effect on the critical discount factor.

left-hand side of the 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, 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, on the other hand, we have an inverted U. Here, increased inequality will 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 $\widehat{I}$, 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. Finally, if one agent is below the inflexion point of the utility function (thus having convex utility) and the other agent is above (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.[12] 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, this makes him relatively less sensitive to the outcome of the game over the common-pool resource. This implies that his critical discount factor becomes less sensitive to changes in the size of his payoff from the common resource. In other words, the critical discount factor in Figure 2 would become slightly smoother.[13]

Having thus established the effects of income inequality on cooperation when utility is S-shaped, I proceed by 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

[12]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.

[13]See Ternström (2001) for further discussion. In what follows here, we assume the "substitution effect" to be too small to have any noticeable effect.

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.[14] The relationship suggested by Dasgupta is non-concave up to a BMI of 18.5, with the point of maximum convexity at a BMI of approximately 15. The relationship is concave above 18.5, with a point of maximum concavity at approximately 20. The reason for the shape of this relationship is that the lower is the level of food intake, the larger is the share of its energy content that must be used to convert food into energy. At high levels of food intake, on the other hand, the body's marginal benefit from additional food is decreasing or even negative.[15]

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 very exact 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, which hinges on the assumption that the own discount factor is constant. However, 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.[16] 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 most likely to have a commitment problem. Shetty and James (1994) present data for the distribution of BMI in a range of countries. This data suggest that, with the exception of India, less than a couple of percent of adults had a BMI below 16 and

[14] 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.

[15] Although translating the relationship into a utility function, we disregard the negative part for obvious reasons.

[16] See, for example, Baland and Platteau (1996).

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.

Shetty and James (1994) also report that Eveleth and Tanner (1976) found the average BMI to be ranging from 19 to 21 among adults in the developing countries they studied. 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 or below 15, we would expect the 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. 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 not have any access to this source of income, and may therefore be 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 could 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.

Below, I examine two different ways of facilitating cooperation in the presence of inequality. First, redistribution of external income will move the agents along the utility curve and thereby change their marginal valuations of cooperating versus defecting and thus, the critical discount factors. Second, changing the rules deciding how the gains from cooperation are distributed among the agents will change the relative gains from cooperating versus defecting in physical terms, and thus also the agents' marginal valuations and critical discount factors.

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 total income more equal.[17] This implies transferring income from the rich to the poor agent, in order to decrease the critical discount factor of whomever is the non-committant 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

$$\delta_{\mathrm{D}}^{s} \leq \delta, \tag{6}$$

with s indicating that a transfer has been made. 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. The size of the income transfer is thus limited by the wish that after the transfer, both agents should be able to cooperate, that is, we have the following cooperation constraint,

$$\max\{\delta_{\mathrm{P}}^{s}, \delta_{\mathrm{R}}^{s}\} \leq \delta. \tag{7}$$

An important distinction should be made here. 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.[18]

From the above section, we know that if both agents' consumption levels are above the point of maximum concavity (BMI $\gtrsim$ 20), it will be the richer agent who has the commitment problem. In this case, an income transfer should go from the rich to the poor, as a means of disciplining the rich. A tradition of alms-giving, donations to religious purposes etc. is one way of achieving this, proportionate income taxes another. However, the solution suggested in Section 4.2 may seem more feasible when the rich have the commitment problem.

When the average consumption level is slightly lower, with the agents' consumption levels on either side of the point of maximum concavity (BMI $\approx$ 20), a mean preserving spread in their income levels will increase both agents' critical discount factors. Here, a mean preserving the concentration of income may be the best remedy, particularly if income inequality is such that both agents' critical discount factors are

[17] Except at extremely low income levels.

[18] Unless, of course, the poorer agent is so poor (BMI $\lesssim$ 15) that a further decrease in his income would actually improve the chances of cooperation.

too high. We may then consider alms-giving from rich to poor users as a solution. Finally, if the users cannot achieve this transfer of income on their own, this is a situation where Robin Hood could really be of use.

When both agents are between the points of maximum convexity and concavity, it is the poor agent who has the commitment problem, and the important thing is that income is transferred to him. 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, in ways discussed in the last paragraph, it is important that the rich agent's income does not decrease too much, or the problem will be reversed. Other ways for the rich of improving the situation of their poor co-users could be favorable agreements on other areas of interaction, for example tenure-, sharecropping- or informal credit contracts.

In the above discussion, we 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, and the transfer can be completely unconditional on the actions chosen in the use of the common resource.[19] We have also implicitly assumed that the transfer is made every period. For this reason, transfers that are part of long-term agreements on other areas of interaction, or embedded in the norms of society, fit the model better. 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.

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 can be a misinterpretation. If the institutional characteristics of management, and not only the physical characteristics of the resource, are considered, an unequal distribution of benefits (or costs) may induce cooperation and can thereby be better 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. If we are thus not to move agent D to another

[19]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, however. Once the transfer has been made, the cooperation of the recipient will follow voluntarily.

segment of the utility function, we need to increase his relative benefit from cooperating in physical terms. 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 exact 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.

We hence let this new strategy prescribe bilateral 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

$$\sum_{t=0}^{\infty} \delta^{xt} \left[U \left(\alpha \pi_{c,c} + K_{\mathrm{C}} \right) + \delta U \left(\alpha \pi_{c,d} + K_{\mathrm{C}} \right) \right.$$
$$\left. + \delta^2 U \left(\alpha \pi_{c,c} + K_{\mathrm{C}} \right) + \ldots + \delta^{x-1} U \left(\alpha \pi_{c,c} + K_{\mathrm{C}} \right) \right] \tag{8}$$

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

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

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

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

and

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

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. Any change in strategies making cooperation possible will be voluntarily adhered to, since it increases the benefit for both agents. Agent D will obtain more than he would by deviating, otherwise he would not choose to cooperate under the new strategy. Agent C will get less than if cooperation had been possible under the old strategy, but since it was not, he will be satisfied with getting more than under non-cooperation.

How often agent D should be allowed to deviate, that is, how large x should be under the modified strategy, will depend on how close the agents' critical discount factors are to the personal discount factor much the agents will gain or lose in the periods that deviation is allowed. Let

ΔU^x_{C} symbolise the change in the gain from cooperation of agent C in period x, and ΔU^x_{D} the corresponding change for agent D, that is,

$$\Delta U^x_{\text{C}} = U\left(\alpha\pi_{c,d} + K_{\text{C}}\right) - U\left(\alpha\pi_{c,c} + K_{\text{C}}\right) \tag{12}$$

and

$$\Delta U^x_{\text{D}} = U\left(\alpha\pi_{d,c} + K_{\text{D}}\right) - U\left(\alpha\pi_{c,c} + K_{\text{D}}\right). \tag{13}$$

If ΔU^x_i 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 ΔU^x_{C}. 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 $|\Delta U^x_{\text{C}}|$, the larger is the loss when this occurs. Finally, the larger is δ, the more important are future payoffs (or losses) 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 ΔU^x_{D}.

Given δ and ΔU^x_i, 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 critical and personal discount factors ($(\delta - \delta^*_{\text{C}})$ is large), his payoff from cooperation can be considerably decreased without making it impossible for him to commit to cooperation. Given ΔU^x_{C}, 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 ($(\delta^*_{\text{D}} - \delta)$ is small), it only takes a small increase in the benefit from cooperation to make him able to cooperate and, given ΔU^x_{D}, $x_{\max}$ 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. In this case, it will not be possible to sustain cooperation, even if the strategy is changed.

To summarise, given δ and the differences in cooperative payoffs under the two strategies, the further agent D is from cooperating, the more frequently he must be allowed to deviate to enable him to cooperate. Similarly, the more slack there is between agent C's critical discount factor and the personal discount factor, the smaller x can be, without making agent C unable to cooperate.

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 indicate a very uneven distribution of benefits, while a large x would indicate the opposite. If we see a very uneven distribution of benefits, we would expect there to be a great difference in the agents' utility from cooperation. This could either be because external income is very unevenly distributed, or because the utility function is very steep in the relevant segment, which would indicate that the agents are at intermediate consumption levels (BMI between 15 and 20). With only a slightly unequal sharing of the benefits from cooperation, we would expect the agents to have fairly equal income levels, be on a fairly flat segment of the utility function, or have unequal incomes but on either side of the point of maximum concavity, so that they happen to give the same critical discount factor.

Having now dealt with the questions of how much more agent D should get and when, we come to the question of who agent D is - the richer or the poorer agent. First of all, we know from Section 3 that agent D will be rich if both agents are above the point of maximum concavity or below the point of maximum convexity of the utility function, that agent D will be poor if they are on either side of the inflexion point of the S-shaped utility function or if both are between the points of maximum and mimimum convexity. and that we cannot be sure if they are both on the concave segment, but at either side of the point of maximum concavity of the utility function. Furthermore, we know from above that if agent D is rich, a positive x implies an allocation of net benefits from cooperation that is proportional to the distribution of income, and if agent D is poor, we have a counter-proportional allocation of net benefits, or, alternatively, a proportional distribution of costs. Thus, in groups with a relatively high average income level (both agents' BMI $\gtrsim 20$) or a very low average income level (both agents' BMI $\lesssim 15$), we would expect that the rich are getting a larger share of the gains from cooperation. If the average income is at an intermediate level (BMI $15 \lesssim$ BMI $\lesssim 20$), we would expect the poor to be getting a larger amount of the benefits (counter-proportional allocation).

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 results of this section are 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. We can thus assume that the groups proportionally distributing benefits are, on average, better off than other groups in Dayton-Johnson's sample, and that their income level should be high enough for their critical discount factor to be increasing in income. For such groups, a distribution of the benefits from cooperation (water, in this case) that is proportional to land-holding size, is in line with the results of my analysis here.

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[20] 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. However, there is a risk that these users were so poor that they would have had a BMI even below 15. Unless all users were so poor, it might still be the case that the poorest have the highest critical discount factor. Furthermore, in such a case, we should also take the effect of threatened survival into consideration.

If we combine the results here with those of Ternström (2001), 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 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 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 D is rich because the average

[20] FAO (2002).

income level is above the point of maximum concavity, it will also decrease agent C's critical discount factor. 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.

Some of the results may seem disturbing. Increasing inequality to achieve cooperation at very low income levels seems inhumane, and policy makers would probably not put cooperation around the common-pool resource on top of the agenda at such low consumption levels. Furthermore, if the discount factor increases when survival is threatened, the results are not applicable to such situations.

It is also 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.

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Incentives or Correlation? Cooperation in Irrigation Systems in Nepal*

Ingela Ternström†

Abstract

Ten irrigation systems in Nepal are analysed in order to find out how cooperation among users is related to incentives and coordination. The study combines statistical analysis with case studies of five of the irrigation systems.

The data contain information for a wide range of variables over a long period of time and gives a direct measure of cooperation.

I find that cooperation is best explained by a combination of incentive- and coordination related variables. The most striking result is the importance of personal leadership. The income level and the share of users belonging to the largest ethnic group are also positively correlated with cooperation. Income inequality and, more surprisingly, the existence of a water users' association, are negatively correlated with cooperation. Cooperation was also lower during the first years of democracy.

Neither the age of the system, the number of users or the ethnic heterogeneity of the users seemed to be of any considerable importance for cooperation.

Key Words: Common-Pool Resources, Coordination, Data Analysis, Case Studies, Irrigation Systems, Leadership, Nepal.

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†The Beijer Institute, The Royal Swedish Academy of Sciences, P.O. Box 50005, SE-104 05 Stockholm, Sweden. E-mail: Ingela.Ternstrom@beijer.kva.se

1 Introduction

When analysing cooperation in common-pool resource management, there are two key questions. First, is it at all possible for users to cooperate? This depends on the incentive structure they are facing and is usually answered by modelling the situation as a non-cooperative game. In principle, if the users do not value the gain from deviating too highly, cooperation is possible in the sense of there existing at least one cooperative equilibrium. However, this does not at all preclude the existence of non-cooperative equilibria. Thus, the second question we must ask is: Among this multiplicity of equilibria, when will the users be successful in picking a good one? This depends on the users' ability to coordinate on one specific equilibrium and they must all know and agree on how the game is to be played. We may expect factors such as the number of users and their homogeneity, the amount of time already spent cooperating and leadership to affect the extent of coordination. In this essay, I make an empirical analysis of the relative importance of different incentive and coordination related variables.

The data used for the analysis have recently been collected in ten irrigation systems in the Terai region in Nepal. Three features make the data set special: It contains information from a number of different points in time throughout the history of the irrigation systems; it contains information on a broad range of physical, institutional and socio-economic variables, and finally; it uses a measure of cooperation that is separate from physical variables such as geography, investments in infrastructure, etc.[1] The analysis combines a statistical analysis of data from the ten systems, with case studies of five of them.

The statistical analysis shows that cooperation is best explained by a combination of incentive and coordination related variables.

The main finding is that leadership plays a key role in making cooperation work. Both the statistical analysis and the case studies indicate that the presence of a person-leader is the most important factor for successful cooperation. Cooperation is also positively correlated with a large share of the users belong to the majority group. The case studies give several examples of how the rulings of the majority group have been challenged as the share of users belonging to other ethnic groups has increased. Contrary to what may be expected, a water users' organisation is negatively correlated with cooperation. A reason for this suggested by the case studies is that the formation of a water users' association is

[1]The NIIS (Nepal Institutions and Irrigation Systems) data base, for example, contains data from a very large number of irigation systems in Nepal, but does not have time-series data. See Lam (1998) for an extensive analysis of the NIIS data set.

quite often a demand from outside, rather than an initiative among the users.

Among the incentive related variables, the average food sufficiency and the distribution of land have significant coefficients in the statistical analysis. A higher food sufficiency and a more equal distribution of land holdings seem to make it easier for users to cooperate. This is in line with previous theoretical results,[2] but is not directly referred to as reasons for cooperation in the case studies. However, there is a strong correlation between the level of wealth and ethnic belonging. Interestingly, none of the factors the age of the system, the number of users, the percentage who owns their land, or the reliability of irrigation seem to be correlated with cooperation. Finally, I find that cooperation was significantly lower in the first years after Nepal had become a democracy. According to the case studies, this was due to an increased politicisation among the farmers.

Before proceeding, let me offer a generalised picture of the irrigation system under study. The typical irrigation system consists of an irrigation canal with its intake in a river. The water may be divided into several branches and sub-branches before reaching the farmers' fields. The amount of water each farmer obtains depends on the amount of water in the river and the state of the canals and intakes, which can be of a more or less permanent structure. The canals can, for example, have no lining at all or cement-lined, and the intake can be made of brushwood or cement. A canal with a brushwood intake and unlined canals will require more repair and maintenance and deliver less water than a permanent intake and cement-lined canals. Depending on their nature, the canals must be repaired and desilted and the intake must be rebuilt or repaired after floods, and the water must be distributed among farmers' fields. For these purposes, the farmers need to cooperate, for example by agreeing on some set of rules for contributing labour and distributing water, and by following these rules.

An irrigation system thus consists of physical as well as institutional structures. The farmers using the system are often organised in a Water Users' Association (WUA), or has a leader making decisions regarding the time and labour contribution for repair and maintenance, the distribution of water and the penalty for not following the rules, for example.

The paper proceeds as follows: Section 2 briefly discusses the theoretical background for the incentive and coordination problems and presents hypotheses. Section 3 presents the data material and discusses the variables chosen for the statistical analysis, which is carried out in Section 4. The results of the statistical analysis and the case studies

[2] Ternström (2001 and 2002).

are discussed in Section 5, and Section 6 concludes. The Data Appendix contains descriptive statistics, the matrix of bivariate correlations and an abbreviated version of the questionnaire. The case studies are presented in the Case Study Appendix.

2 Theoretical Background and Hypotheses

2.1 The Incentive to Cooperate

The management of common-pool resources is often analysed using non-cooperative game theory. By studying the users' incentives to cooperate, i.e. comparing what they get if they cooperate with what they can gain by deviating, we can find out whether it is at all possible for them to cooperate.[3] The utility of taking the different actions depends on the relative size of their physical payoffs and the users' valuation. In the case of irrigation systems, the physical payoffs are crop sizes, which are decided by factors such as land size, soil and canal conditions, water availability and reliability and the crops used. The cost of not cooperating, that is, the cost of breaking rules for labour contribution or water distribution, is determined by the punishment for such behaviour.

If a given increase in the material payoff is valued differently by an individual on the brink of starvation than by an individual with a surplus, the level and distribution of income will also affect the users' ability to cooperate. Ternström (2001, 2002) relates the ability to commit to cooperation to the body mass index (BMI),[4] by assuming health to be a strong component in the utility function. The farmers in our data live in the Terai area of Nepal, where 40 percent of the population have a BMI below 18.5.[5] For such poor people, the results in Ternström (2001) make us expect that there should be a positive correlation between income level and cooperation, and Ternström (2002) suggests that income inequality should have a negative effect on cooperation.

The valuation of future benefits will depend on how likely they are to be encountered. We may thus expect a user owning his land to have a longer time horizon for benefits stemming from the land and he should therefore be more keen to avoid conflicts with his co-users and do his share of maintenance work in the system, than a tenant or share-cropper.

[3] See, for example, Fudenberg and Tirole (1991) on game theory and Ostrom, Schroeder and Wynne (1993) for a discussion on incentives in developing countries.

[4] The body mass index is calculated as a person's weight divided by the square of his height.

[5] FAO (1998).

Hypotheses on Incentives We expect to find a positive correlation between cooperation and land ownership, the additional harvest that can be gained by deviating, and income level, and a negative correlation between cooperation and the cost of deviating and income inequality.

2.2 Coordinating on a Good Equilibrium

The mere fact that the irrigation systems under study are actually functioning (although not always perfectly well) suggests that there exist cooperative equilibria in them all. We now turn to the problem of getting all users in an irrigation system to coordinate on the same cooperative equilibrium. It must be decided on which equilibria to coordinate, this information must be communicated to all users and all users must interpret the information in the same way. An efficient decision-making body facilitates the first part (for example leadership in the form of a person or a group, or a well-functioning democratic process). Communication is facilitated if users talk the same language and are easily reached, and consistent interpretation is more likely if they have a more homogeneous background.

Alesina and La Ferrara (2002) discuss how racial and ethnic homogeneity are related to trust in a community, and Knack and Keefer (1997) discuss the importance of trust and social capital for economic performance. The number of users and ethnic groups, and the time they have been working together (age of the system) can all be expected to affect homogeneity and thus, communication and interpretation.

Leadership is a subject that has been less discussed both in the literature on common-pool resource management and in non-cooperative game theory. Kreps (1990) introduced the topic and more recently, Meyer (2000), for example, discusses the possible role of a "good leader" in increasing an agent's perceived likelihood that other agents will cooperate, and thereby increasing the likelihood that there will actually be cooperation. Shukla, Joshi and Devkota (1999) suggest leadership to be a crucial question when transferring the management of irrigation systems from the government to the farmers.

Hypotheses on Coordination Based on the above discussion, we would expect to find a negative correlation between cooperation and the number of users, and a positive correlation between cooperation and the age of the system, ethnic homogeneity and a powerful leadership.

3 The Data

The data have been collected by a team at the Water Management Study Program (WMSP) at the Institute of Agriculture and Animal Science, Tribhuvan University in Rampur, Nepal. The data collection was initiated in May 1998, but the main part of the work was carried out in 2000 and 2001.

The questionnaire was developed in collaboration with WMSP staff after a series of field visits, and tested and modified accordingly. Data were collected in discussions with groups of key individuals in each system. In many cases, the respondents were members of the Executive Committee of the Water Users' Association.[6] Wherever possible, the given information was crosschecked and complemented by written records.

In the discussions, considerable effort was put into getting the respondents' explanations to what had occurred. The purpose was to obtain as accurate a picture of the connections shaping the history of the systems as possible, to have a way of verifying the credibility of the information given by the respondents and capture as much of the information not covered by the questionnaire as possible. The result is a data set that does not only contain figures, but also a large amount of background information and a very detailed description of the intricate connections between different variables. In the analysis of the data, I will use both the numerical and the narrative information.

Irrigation systems were selected on the criteria that they be farmer managed, located in similar environments, have a fairly long history and preferably, some written records. These selection criteria will have affected the sample by only including systems that are functioning at present and have also been functioning for some time. Systems with too severe cooperation problems will thus be excluded from the sample.

The data was collected in three neighboring districts, Chitwan, Makwanpur and Nawalparasi, in the Terai region of Nepal. The land was formerly under jungle forest, and most of it was not inhabited until malaria was eradicated in the 1950's. In a few places, however, Tharus, who are the original inhabitants of the area, had developed settlements and irrigation canals long before that date. With the eradication of malaria, the construction of the East-West Highway and the government's resettlement and land titling program in the 1950's and 60's, people from the hilly areas started to move in, which caused a period of rapid population growth. After the main inflow of migrants, the increase in the number

[6] There is therefore a risk that the information has a positive bias for periods when the respondents themselves were in power.

of households has mainly been due to family separation, when ancestral land has been distributed among the sons of each generation.

There has been a series of government and/or non-government organisation supported programs for improving the infrastructure of the irrigation systems, for example the Irrigation Line of Credit (ILC), the Nepal Irrigation Sector Project (NISP), the Farm Irrigation and Water Utilisation Division (FIWUD) and the East Rapti Irrigation Project (ERIP). Most of these programs have required users to contribute a (small) share of the total cost in the form of cash and/or labour.

Note that all years are given in Bikram Shah (B.S.) according to the Nepali calendar. To get the year in A.D., subtract 57 from the given year.

The data set contains information on a large number of variables divided into eight main categories. The respondents were first asked to develop a time line over the main events in the history of the irrigation system. These events were then used as reference points when asking for historical information. This way of collecting historical data makes the information less reliable than if there had been written records on all the information needed. There will be a bias for historical records, since some households and other data will have been forgotten.

The *time line* tracks the main changes in the irrigation system and its users over time. The *general characteristics* of the irrigation systems are described by variables such as the system's age, command area, cropping pattern, irrigation availability and reliability, cropping intensity and access to markets. Regarding the *users of the systems*, there is information on the total number of households and the number of households belonging to different ethnic groups, the users' income from cash crops and outside income sources (labour, service, tractor, poultry, etc.).

The *users' income level* is captured by information on their housing standard, the size of landholdings and food sufficiency (in terms of months per year covered by their own agricultural production). The *distribution of income* among users is measured by information about the distributions of land, housing and food sufficiency, as well as by users' subjective estimate of the number of rich, poor and average households. There is a large amount of information on the *institutional structure* of the irrigation systems and their development over time, including leadership, the Water Users' Association, rules about fines, fees and labour contribution, etc. Finally, there is a number of *trend lines* describing the extent of rule breaking, conflicts and monitoring over time. For some of the major changes in the systems, like major infrastructure investments, there is also information on the *marginal effects* on different categories of users.

Obviously, not all information in the data material will be used in the present analysis. The extensive amount of data, together with the detailed narrative information, provides plenty of opportunities for further studies of the functioning of these irrigation systems.

3.1 Choice of Variables

For the purpose of the present analysis, I will focus on the following variables. See Table 1 in the Data Appendix for descriptive statistics.

Land Ownership Land ownership is measured as the share of users owning all the land they till. This excludes sharecroppers, tenants and also those who are both owners and share-croppers, since the size of their owned land tends to be very small.

Water Reliability For an indication of how much the farmers can gain by taking more than their agreed share of water, I use the reliability of water flow. As the fine for not contributing labour to maintenance has, almost without exception, been equal to the wage for day-labour, there is very little variation in the variable and it will not be included in the analysis.

Average Food Sufficiency There are mainly two options for measuring the consumption level of the users, their average food sufficiency and average landholding size. Average land holding size does not give a correct measure of consumption, as crop productivity has been changing quite drastically over time. The variable food sufficiency tells us to what extent the households' annual consumption need is covered by their own agricultural production, but there is a risk that this measure is not independent of cooperation. However, this does not seem to be a major problem in our data; see further in the discussion on food sufficiency in Section 5 below. For these reasons, I will use average food sufficiency rather than average landholding size.

Land Size Distribution The distribution of land holdings, measured by the variable land gini, is selected for representing the users' income distribution. The different measures of inequality are strongly correlated, and this is the variable least correlated with average food sufficiency.

Personal Leadership This variable indicates whether a person has been taking a key role in the leadership of the irrigation system. There was no direct question about the presence of a person-leader in the data. The information on this variable was found in the narrative information about the institutional structure, rule enforcement, time line etc.

Water Users' Association The variable is a dummy variable for the presence of a WUA, which is another type of leadership.

Number of Households Indicates the number of users.

Age of the Irrigation System Indicated by the number of years since irrigation became possible, thus not since the farmers started cooperating in the effort of getting irrigation.

Majority Strength I let ethnic homogeneity be represented by the share of users belonging to the largest ethnic group. Using the number of ethnic groups would be problematic, both because this is correlated with the number of users, and because some ethnic groups only have one or a few representatives.

Democratisation Process Dummy In 2046 (1990 AD), Nepal went from being a monarchy to a democracy. The transition had extensive implications for the political life also on the local level, which is likely to have disturbed cooperation in the irrigation systems. The variable takes the value of one for the years 2045 to 2050.

4 Statistical Analysis

The analysis builds on data from the ten irrigation systems and case studies of five. The five irrigation systems included in the case studies were selected on a "first come first serve" basis. They were simply the systems for which I received data first. However, they do represent a fairly broad variety of systems. Some very old and some fairly young, some with personal leaders and some with only WUAs, some successful and some not, some with a positive and some with a negative trend in cooperation, some by the original inhabitants and some started by new settlers. The case studies are presented in the Case Study Appendix.

The section starts with a statistical analysis of the data from ten (nine) systems.[7] The results are then discussed in the light of the information given in the case studies. However, first of all I present the dependent variable.

In studies of irrigation systems, indicators of physical performance, such as the amount of water or the maintenance needed, are often used as the dependent variable. However, performance depends on a combination of factors such as geography, government and private investments, and cooperation. Thus, although physical performance indicates how well the irrigation system functions, it is an imperfect measurement of how well the users cooperate. Since the focus of the present study is on cooperation among users rather than the performance of the irriga-

[7] For one of the irrigation systems, Pithuwa, there is no information about personal leadership. The observations from this system are therefore excluded in parts of the statistical analysis.

tion systems, I have chosen to use as direct a measure of cooperation as possible. Thus, cooperation is defined as the absence of conflicts and rule breakings among users and the cooperation index is based on trend lines for rule breaking and conflicts, drawn by the respondents.[8] When interpreting the cooperation index, we should keep in mind that it is a subjective index, thus two systems with the same number of rule breakings may have assigned it different values, depending on whether it is high or low as compared to their usual or previous amount of rule breaking.

Figure 1 shows the development of cooperation in the ten irrigation systems over time. Two systems, Jayashree and Baise, show continuously increasing levels of cooperation, while in Nawalpur, cooperation has slowly been decreasing over time. The other seven systems have all started out with a fairly high degree of cooperation, which decreased around the mid-2040's and then increased again at the end of the 2040's.

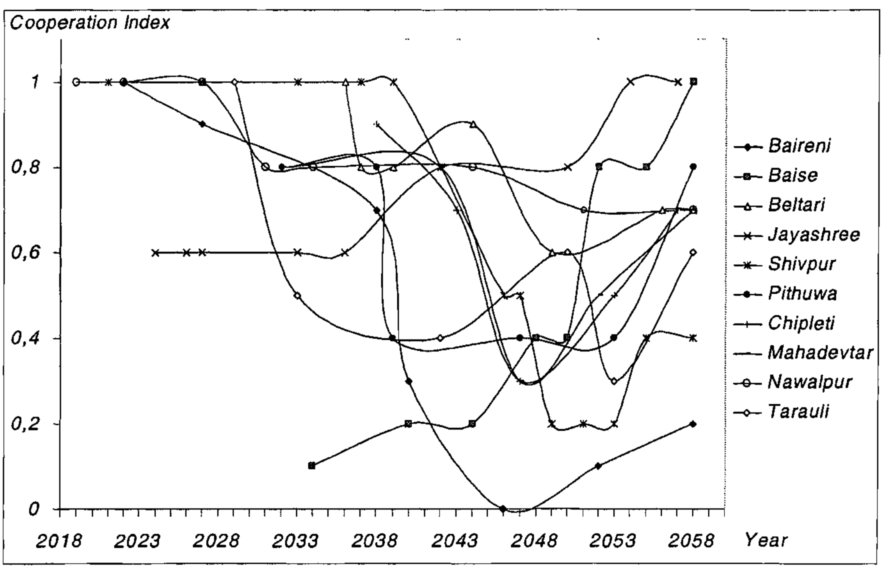

Figure 1: The Development of Cooperation over Time. Note that for illustrative purposes, the observations have been connected with "smoothed lines", this makes it look like the Cooperation Index is sometimes above 1 or below 0.

[8]Trend lines on a 0 to 5 scale for rule breaking (breaking the rules for labour contribution or water distribution) and conflicts (conflicts or disputes among the users). $Cooperation\ Index = \frac{10-(rulebreaking+conflicts)}{10}$.

4.1 Choice of method

When analysing the data, I have used Panel data methods. As the data consist of a relatively small number of observations for each irrigation systems, this was judged to be the most suitable method. Since both the number of irrigation systems and the total number of observations are small, and the observations are made in different years in different systems, the one-way fixed effects error component model was used.[9] The regression was run in Limdep 7.0.

4.2 Results

I have made separate regressions for coordination (Equations 1 and 2) and incentive related (Equation 3) variables, in addition to regressions combining both types of variables (Equations 4, 5 and 6). The number of observations is smaller for regressions including the variable person-leader, since there are no data for this variable for one of the systems (Pithuwa).[10] Three other observations had extreme values for average food sufficiency and were also excluded from the sample. The results of the regressions are presented below.

[9]This limits the extent to which we can draw conclusions about other irrigation systems based on the results here. However, the irrigation systems I study do not show signs of being exceptional in any way, and the case studies provide a deeper understanding of the results.

[10]Excluding this system in the remaining equation did not considerably change the results.

Dependent Variable: Cooperation Index

	Coordination		*Incentives*	*Coordination and Incentives*		
	Equation 1 (n=57)	*Equation 2 (n=57)*	*Equation 3 (n=63)*	*Equation 4 (n=57)*	*Equation 5 (n=57)*	*Equation 5 (n=57)*
Independent Variables						
Person-Leader	0.306***	0.324***		0.289***	0.245***	0.261***
	3.574	*3.773*		*4.033*	*3.307*	*3.300*
WUA	-0.176**	-0.189**				-0.035
	-2.065	*-2.156*				*-0.357*
Majority Strength	0.517*				0.498**	0.314
	1.794				*2.128*	*0.881*
Ethnic Fragmentation		-0.305				
		-1.216				
Average Food Sufficiency			0.576***	0.423**	0.567***	0.465***
			3.024	*2.461*	*3.947*	*2.512*
Land Gini			-0.342*	-0.338**		-0.144
			-1.855	*-2.137*		*-0.515*
Democracy Dummy	-0.178**	-0.176**	-0.180**	-0.183**	-0.201***	-0.186***
	-2.218	*-2.162*	*-2.377*	*-2.644*	*-2.950*	*-2.639*
Adjusted R2	***0.4847***	***0.4662***	***0.4883***	***0.6435***	***0.6432***	***0.6336***

****** Significant at the 1 percent level*
***** Significant at the 5 percent level*
*** Significant at the 10 percent level*
t-ratios below coefficients

Table 1: Regression Results.

The variable with the highest overall level of significance is the person-leader. It has t-ratios ranging from 3.3 to 4.0, depending on the specification of the model, giving it a significance level below 1 percent. The coefficient for person-leader is around 0.3, which implies that, ceteris paribus, the presence of a person-leader increases the cooperation index by 30 percentage points.

The presence of a WUA, on the other hand, decreases the cooperation index by about 0.18. This coefficient is significant at the 5 percent level. The strength of the majority group seem to have a very strong effect but is significant only at the 10 percent level in Equation 1. If the share of users belonging to the majority group decreases by 10 percentage points, the cooperation index decreases by 5 percentage points.

A six month increase in average food sufficiency is connected with an increase in the cooperation index of about 0.25. This coefficient is also highly significant (significant at the 5 or 1 percent level). The coefficient for the gini variable for land distribution is significant at the 5 or 10 percent level, and implies that an increase in the gini coefficient of 0.1 is correlated with a decrease in the cooperation index of 0.03.

The coefficient for the democratisation dummy shows that the cooperation index was about 0.2 lower during the years of the democracy movement. The coefficient is significant at least at the 5 percent level.

Equation 1, testing only coordination related variables, has an adjusted R^2 of 0.48. For the sake of comparison, an ethnic fragmentation index à la Alesina and La Ferrara (2002) was calculated and tested in Equation 2.[11] As the coefficient for the ethnic fragmentation index is not significant, the result confirms that the strength of the majority group rather than ethnic homogeneity is of importance. Equation 3 shows the two significant incentive related variables, with almost exactly the same adjusted R^2 as the first equation.

When coordination and incentive variables are combined, in Equations 4 and 5, the adjusted R^2 increases to 0.64. The analysis thus shows that both incentive and coordination related variables are of importance for cooperation. For the sake of illustration, I have included all variables from Equations 1 and 3 in Equation 6. In Equations 4 and 5, I choose not to include WUA, since the interpretation of this variable is problematic for reasons discussed in Section 5 below.

5 Discussion

Below, the results of the statistical analysis are discussed in the light of the information provided by the case studies. From the bivariate correlation matrix in Table 2 in the Data Appendix, it is obvious that there is a substantial amount of correlation between the independent variables. This, together with the small number of observations, makes it necessary to be cautious when interpreting the data. There is also a risk of interdependency between the dependent and some of the independent variables. For example, a high degree of cooperation may affect the flow of water in the canal and thereby, the productivity of the farmers' fields. It is thus important to keep in mind that the data analysis gives us information about the correlation between variables, but not necessarily the direction of the relationship.

[11]The index represents the likelihood of encountering an individual belonging to a different ethnic group. See Alesina and La Ferrara (2002).

5.1 Consumption Level

The mean food sufficiency for the whole sample is almost exactly one year, thus the users have, on average, been able to produce just enough food to cover their basic consumption needs. The income distribution is such that it is often a small fraction of the households that produces a surplus, with the majority being food sufficient or deficient. The result shows the expected positive correlation between consumption level and cooperation. Although the few observations prevents us from doing it, it would be interesting to see if there has been a weaker correlation between cooperation and income level in the richer systems, as would be expected from the results in Ternström (2001).

As the purpose of irrigation is to increase consumption, we need to be very careful before making any assumptions about the direction of the causality. Is it increased cooperation that leads to better irrigation systems and thereby to a higher food sufficiency, or is it a higher food sufficiency that makes the users less desperate and less focused on short-term gains and thereby, makes it easier for them to cooperate? The way cooperation is defined is an attempt at minimising the risk of such interdependency. To test the result of this attempt, I ran a regression with food availability as the dependent variable. After a gradual exclusion of the least significant variables, the following equation, with an adjusted R^2 of 0.84, remained: Average food sufficiency = 0.174×(average land holding size) - 0.615×(food gini) + 0.062×(water reliability) - 0.458×(majority strength). All variables are significant at the 1 percent level.

There has been extensive changes in agricultural production over the years, and my guess is that cooperation played a larger role for food sufficiency in the early days. The cooperative efforts often started with the actual construction of an irrigation canal. The case studies indicate that initially, the benefits from irrigation must have been very high. In Beltari, for example, it took the users 20 years, four attempts and substantial amounts of effort to even get irrigation, and they obviously thought it was worth the effort. At that stage, cooperation no doubt had a considerable effect on food sufficiency. However, the statistical analysis does not include data from periods before irrigation actually began.

5.2 Income Distribution

There is a significant and negative correlation between cooperation and the extent of inequality in the distribution of land. This supports the hypothesis that an unequal distribution of income has a negative effect on coöperation. Lam (1998) obtains the same result when analysing the data in the NIIS data base, and Dayton-Johnsson (2000) finds the same in Mexican irrigation systems. The reason stated in Ternström (2002) is that differences in the income level cause differences in the marginal valuation of cooperation. Here, the case studies show that there may also be other reasons. There seems to be a correlation between the size of the land holding, the source of outside incomes and ethnic belonging. While large holding households often have service jobs, smaller ones tend to complement their agricultural production with income from less well paid sources, such as being porters or working as day labour in road constructions or industries. This accentuates the differences and thus the variable land gini may capture more than just the distribution of land. Since it is income distribution we are interested in here, this serves our purpose well.

Interestingly, the development over time seems to allow users to make their contribution to maintenance in cash instead of in kind. As richer users have a higher opportunity cost of labour (as they are often better educated and have more highly paid employments), this decreases their relative cost of cooperating. This may be interpreted in terms of Ternström (2002), as a way of enabling the richer agents to continue cooperating, even though their higher income level makes them less interested in doing so.

5.3 Personal Leadership

The variable emerges as highly significant in the statistical analysis, and if I were to pick out one single variable on the basis of the case studies alone, it would be the presence of an individual taking a personal responsibility for running the irrigation system. There are several statements in the case studies such as "the users feel that this person is crucial for the smooth running of the system" (Jayashree).

Notwithstanding if the person-leaders are appointed by the users or came with the feudal system (the Zamindars), they are often trusted and respected among the users. There is no evidence in the case studies of an elected leader being better than a "feudal" one. At least in theory, there is a difference in that the elected leaders can always be elected away, while the feudal leaders could not be as easily dismissed. Thus, it can be argued the power of elected leaders should be weaker than that of feudal leaders. On the other hand, the power of feudal leaders is tied to the feudal system and, like in Baireni, the end of the feudal system can remove the basis for the power of such a leader.

With both types of leaders, there are statements in the data such as "no one dares to break the rules as they are so strictly enforced" (Baireni), which points to a strict rule-enforcement. However, this seems to have been combined with an extensive involvement in the day-to-day management of the irrigation system. The person-leaders often spend a large amount of their own time drawing up irrigation schedules, supervising water distribution, planning maintenance work, etc. (see, for example, Jayashree). This may be a reason why there are not person-leaders in all systems, which could be expected considering how successful this strategy is for making cooperation work. Being a person-leader takes considerable effort and is highly time-consuming. This "additional cost" for the leader of getting irrigation may be outweighed if he has considerably larger landholdings and thus, can get a larger gain from irrigation, than other farmers (as suggested by Wade (1988). However, the case studies show that a person-leader can also be found among the poorer users.

Many of the person-leaders have held their positions for long time-periods (40 years in Baireni, 25 years in Jayashree, 21 years in Shivpur), and some are still in power. There is even one example where the leader has wanted to resign several times, but where each time, the users have persuaded him to continue since they find him irreplaceable (Shivpur).

The correlation matrix indicates a quite strong correlation between the variable person and some other variables, however, among these the average food sufficiency. There is thus a risk that the variable person also captures something else. Weber, Camerer, Rottenstreich and Knez (2001), examining the "illusion of leadership", found that in an experimental setting, the effect of a small group was often mistaken for a the effect of a good leader. As discussed below, there are no signs of a group-size effect in my case studies. The most plausible source of misattribution instead lies in the consumption level. Could there be a risk that a higher consumption level, caused by completely different reasons, is attributed as an effect of good leadership, and that this is why the person-leaders are so highly praised? Based on the type of comments regarding leadership, this should not be the case. The merit of the leaders is not referred to as being related to the level of agricultural production or even the amount of water in the canal, but rather as being good at developing and enforcing rules and avoiding disputes among users.

We may also ask whether there are other factors, not visible here, making certain irrigation systems more prone to having a person-leader *and* being successful in cooperating. However, this does not seem to be the case as there are also examples of irrigation systems where there was initially no person-leader and cooperation worked badly, while after the appointment of a person-leader, cooperation improved significantly

(Baise).

In the irrigation systems studied here, there have been a number of changes over time and, as discussed by Meyer (2000) regarding leaders in transition economies, there has certainly been a role for the leaders in coping with the changes. Shukla, Joshi and Devkota (1999) discuss the role of leadership in another type of change, the transfer of the management responsibility of government managed irrigation systems to the users. My case studies show that changes can also result in a change of leaders, however.

5.4 Majority Strength

The strength of the majority group is significant at the five percent level, with a positive coefficient of 0.5, which implies that a ten percentage points increase in the strength of the majority group is connected with a five percentage points increase in cooperation. This is quite a strong effect and it is supported by the case studies, which give several examples of cooperation being disrupted when there is an increase in the share of users belonging to other ethnic groups. The interpretation is that it is more difficult to get the users to "play the same game" when they belong to different ethnic groups.

In Baireni, the conflict between Hill and Terai people went so far as to the Terai people being physically beaten while trying to prevent the Hill people from using water from the canal. The Hill people, in turn, had refused to contribute their share of labour in the maintenance work. In this case, the land of the Hill people was located at the head end of the canal, which made them less dependent on the maintenance of the rest of the canal.[12]

The most common source of disputes between groups of different ethnic origin seems to be what is a fair distribution of labour. While the tradition among Terai people has been that all able men in all households should contribute their labour at the time of maintenance work, the view among Hill people is that labour should be contributed on the basis of landholding size.[13] Assuming that the traditions among Terai people have their roots in a feudal system, where the local landlord was often the person in power, this way of distributing labour input implies that richer users get a larger share of the net benefits from cooperation than poorer users. According to Ternström (2002), this is what should be expected when the users are either fairly well off, as was often the case in the early days when land was not so limited, or when they are all

[12] For a discussion of this topic, see, for example Ostrom and Gardner (1993).

[13] See also Lam (1998).

extremely poor.

5.5 WUA Leadership

The results of the statistical analysis show a negative correlation between the existence of a WUA and cooperation. In the case studies, we find a plausible explanation for this unexpected result, since the presence of a WUA does not always indicate a well-functioning decision making body. First of all, it has often been a requirement to have a formally registered WUA to be eligible for support under the different rehabilitation and improvement programs. Thus, the existence of a WUA, even if it has a well defined and formalised set of rules, might very well be just a paper product, or a forced change in traditionally well-functioning forms of cooperation. Baise is an example of this. Here, the WUA was formalised in connection with the ERIP supported canal improvement. However, despite there being elaborate rules for labour contribution and how to punish rule breaking, it was not until a person-leader was appointed that people actually started following the rules. Another example is Beltari, where a WUA was formed in 2034 for the purpose of organising the rehabilitation of the irrigation system, but did not have the capacity (nor the intent) to take responsibility for the day-to-day management of the system after the work had been completed.

There are also cases where the WUA has been formed at the farmers' own initiative for the sole purpose of managing the system and, in some systems, there has been a functioning WUA for a very long time. However, Beltari seems to be one of the few examples of a well functioning WUA that has not also had a strong chairman.

5.6 Democratisation Process Dummy

The significance of this variable confirms that the democratisation process had a negative effect on cooperation. The case studies mention increased politicisation as the cause of decreased cooperation in several places. Naturally, there is a risk that there were also other effects during this period. However, running the regressions without the dummy does not markedly change the results for the other variables.

5.7 Water Reliability

Although water reliability has the incorrect sign and is not significant judging from the correlation matrix, it is mentioned the case studies. However, there are examples showing that both scarcity and surplus can be conducive to cooperation, but also that scarcity increases the temptation to water stealing. In Shivpur, the users used to cooperate well in the use of what little water there was in the early days, while in Jayashree, there were instances of water stealing when water was very scarce. Thus, the case studies give no clear indication of the effect of water scarcity. The comments of there being fewer instances of taking water out of turn when water is highly reliable and available seem quite natural, since it is then more likely that users have enough water for their fields anyway.

5.8 Ownership

Judging from the case studies, the question of ownership is not considered as an important factor for achieving cooperation. This might be due to the fact that even if a farmer does not own the land he tills, he has other strong ties to the area. In the correlation matrix, ownership is not significant but it does have the right sign. The variable "owners" only includes farmers who own all the land they till, thus not those with some own and some share-cropped land. This distinction was made since the case studies indicate that the reason for being a "mixed" farmer is that the own land is very small, and thus, their stake as owners would thus also be very small.

5.9 Age

Already from Figure 1 it is obvious that the age of an irrigation system does not seem to have a positive effect on cooperation. The most common feature regarding the development over time seems to be the decrease in cooperation around 2045-2050. This coincides with the period of democratisation, and the case studies strongly suggest that an increased politicisasion among the farmers is an important reason for the conflicts and disputes during this period.

The fact that time does not seem to be positively correlated with cooperation is not quite what we expected. For example, Ostrom (1990) gives examples of common-pool resource management systems, that have been functioning for very long time and are still functioning very well. However, these systems may also have had their ups and downs in cooperation, rather than improving over time.

From the case studies, I find that in the oldest systems, there has been a regime shift from a feudal to a more democratic system over time. In the old days, the local landlord (Zamindar) was the leader of the people in the village on most issues. The case study of Baireni Kulo gives a good example of this shift. There, the irrigation system was initiated some hundred years ago by the person who was then the

Zamindar. Sixty years later, the system was still run by a Zamindar, who provided leadership for the users for forty years. In the early days, his leadership was so powerful that the users did not dare break any rules. Over time, people from the hilly areas settled in the system area, however. These people have different traditions and did not accept the Zamindari leadership in the same way as the original inhabitants. After their settlement, the Zamindar gradually lost his power until he was finally dismissed after the democratisation of the country. In connection with the breakdown of the Zamindari system, there were intense conflicts between people with Hill and Terai origin, respectively.

Since a considerable part of the Terai used to be under a feudal system, irrigation systems in this area with a long history are likely to have experienced similar shifts in governance systems. Systems that were initiated by the immigrants on the other hand, like for example Baise, have not had to take that struggle.

Ideally, to test whether age is a significant variable in explaining cooperation, we should focus on irrigation systems that have not been subject to this kind of disturbances.

5.10 Number of Households

From Table 3, we see that the number of users have varied greatly between systems and over time. Some systems started out as very small (for example Baireni, Baise and Tarauli), while others had many users already at the initiation of irrigation (Beltari and Chipleti). In most systems, the number of users has increased dramatically, while in Shivpur, for example, the increase has been quite small. There does not seem to be any strong connection between the number of users and cooperation, but there is a connection between the number of households and average land holding sizes, and between average land holding sizes and average food sufficiency. Thus, there is an indirect link between the number of users and cooperation.

From the case studies, we find that there are two reasons for the increase in the number of users, immigration and household separation. A large part of the inflow of new settlers came in connection with the government's resettlement program in the 2020's, which included the eradication of malaria. After the mid 2040's, most of the increase in the number of households has been due to household separation when ancestral land has been distributed among the sons of each new generation. Although the number of observations prevents me from making a careful statistical analysis here, it would be interesting to see if an increase in the number of users has different effects depending on whether it is due to immigration or household separation. The case studies strongly suggest this to be the case.

6 Concluding Remarks

The results of the statistical analysis show that cooperation is affected by both coordination and incentive variables. The case studies emphasise the importance of the coordination related variables. This may, however, be due to the fact that the connection between coordination related variables, such as leadership and common traditions, is more tangible than the incentive related variables. Furthermore, as mentioned above, as users actually cooperate, the incentive problems are not prohibitive.

The most startling result is perhaps just how important leadership seems to be for the users' ability to cooperate. From the case studies, it is obvious that a strong leadership and, in particular, a strong leader, are what the users regard as the most crucial factors for how well cooperation works. The strength of the majority group (but not ethnic homogeneity *per se*) is another factor that has greatly affected the users' ability to cooperate.

Another interesting result is that a water users' association is not necessarily good for cooperation, but this may be because it is not synonymous with a well-functioning decision-making body.

I also find neither age nor the number of users to have any significant importance for the success of cooperation. However, the longer an irrigation system has existed, the larger is the number of changes to which it has been exposed. One such change is the democratisation process, which has had a markedly negative effect on cooperation.

I find the expected positive correlation between income level and cooperation, and negative correlation between income inequality and cooperation. This confirms the underlying assumptions of Ternström 2001 and 2002 that utility is not a linear function of consumption.

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Data Appendix

Table 1. Descriptive Statistics for Selected Variables

	N	Minimum	Maximum	Mean	Std. Deviation
Coopind	66	,10	1,00	,6667	,27419
Age	66	,00	93,00	25,2273	19,40325
Hhno	66	6,00	400,00	119,7121	95,23166
Majstren	66	,21	1,00	,7070	,21092
Person	60	,00	1,00	,5667	,49972
WUA	66	,00	1,00	,7727	,42228
Wreliab	66	,00	5,00	3,3485	1,18312
Owners	66	,07	1,00	,8146	,17911
Foodavg	63	,44	1,67	1,0169	,25317
Landgini	66	,00	,83	,6145	,22736
Demodumy	66	,00	1,00	,1364	,34580
Valid N (listwise)	57				

Table 2. Matrix of Bivariate Correlations

		Coopind	Age	Hhno	Majstren	Person	WUA	Wreliab	Owners	Foodavg	Landgini	Demodumy
Coopind	Pearson Correlation	1	-,156	-,074	,450**	,292*	-,412**	-,168	,065	,508**	-,410**	-,325**
	Sig. (2-tailed)	,	,211	,556	,000	,024	,001	,179	,602	,000	,001	,008
	N	66	66	66	66	60	66	66	66	63	66	66
Age	Pearson Correlation	-,156	1	,420**	-,097	,065	,174	,481**	-,159	-,088	,065	-,016
	Sig. (2-tailed)	,211	,	,000	,439	,620	,164	,000	,202	,491	,601	,898
	N	66	66	66	66	60	66	66	66	63	66	66
Hhno	Pearson Correlation	-,074	,420**	1	-,181	-,398**	,558**	,211	-,111	-,526**	,506**	,072
	Sig. (2-tailed)	,556	,000	,	,147	,002	,000	,089	,374	,000	,000	,564
	N	66	66	66	66	60	66	66	66	63	66	66
Majstren	Pearson Correlation	,450**	-,097	-,181	1	,428**	-,314*	-,152	,306*	,356**	-,381**	-,160
	Sig. (2-tailed)	,000	,439	,147	,	,001	,010	,222	,012	,004	,002	,199
	N	66	66	66	66	60	66	66	66	63	66	66
Person	Pearson Correlation	,292*	,065	-,398**	,428**	1	-,350**	,237	,348**	,468**	-,319*	-,053
	Sig. (2-tailed)	,024	,620	,002	,001	,	,006	,068	,006	,000	,013	,689
	N	60	60	60	60	60	60	60	60	57	60	60
WUA	Pearson Correlation	-,412**	,174	,558**	-,314*	-,350**	1	,130	-,399**	-,639**	,705**	,215
	Sig. (2-tailed)	,001	,164	,000	,010	,006	,	,298	,001	,000	,000	,082
	N	66	66	66	66	60	66	66	66	63	66	66
Wreliab	Pearson Correlation	-,168	,481**	,211	-,152	,237	,130	1	-,113	,044	,204	,070
	Sig. (2-tailed)	,179	,000	,089	,222	,068	,298	,	,367	,732	,100	,576
	N	66	66	66	66	60	66	66	66	63	66	66
Owners	Pearson Correlation	,065	-,159	-,111	,306*	,348**	-,399**	-,113	1	,105	-,327**	-,039
	Sig. (2-tailed)	,602	,202	,374	,012	,006	,001	,367	,	,413	,007	,753
	N	66	66	66	66	60	66	66	66	63	66	66
Foodavg	Pearson Correlation	,508**	-,088	-,526**	,356**	,468**	-,639**	,044	,105	1	-,568**	-,111
	Sig. (2-tailed)	,000	,491	,000	,004	,000	,000	,732	,413	,	,000	,388
	N	63	63	63	63	57	63	63	63	63	63	63
Landgini	Pearson Correlation	-,410**	,065	,506**	-,381**	-,319*	,705**	,204	-,327**	-,568**	1	,172
	Sig. (2-tailed)	,001	,601	,000	,002	,013	,000	,100	,007	,000	,	,167
	N	66	66	66	66	60	66	66	66	63	66	66
Demodumy	Pearson Correlation	-,325**	-,016	,072	-,160	-,053	,215	,070	-,039	-,111	,172	1
	Sig. (2-tailed)	,008	,898	,564	,199	,689	,082	,576	,753	,388	,167	,
	N	66	66	66	66	60	66	66	66	63	66	66

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Abbreviated Version of Questionnaire

Study of the Dynamics of Irrigation System, Check-list

1. Time Line

Develop a time line for major events that the people using the irrigation system can remember. These events can be both external (migration, flood, draught, change in source, change in labor market, etc.) or internal (forming the WUA, appointing chaukidar for the first time, starting to pay water guards, etc.).

2. General Characteristics

Name of the branch system:
Name of the main system
Name of source:
Started year
Command area:
Location (Head, Middle or Tail of Main system):
Cropping pattern (Monsoon , Winter , Spring)
Water availability (% of area irrigated)
Water reliability (1-5 scale)
Cropping intensity (percent)
How is water allocated (rotation ? Head to tail ?)
Nearest marketplace: Name, How do most people get there, Distance in time

3. Users of the irrigation system

Number of households using the branch system
Ethnic and religious groups (no. of households by ethnic groups and castes)
Income from cash crops (%or no. of households) and average share of those hh's total income coming from cash crops
Income from other sources (type of income, no of households and % of their income)

4. Level of wealth of the households using the irrigation system

Roofing and building material (Permanent, Semi permanent or Temporary)
Landholdings: (no. of households) (Owner cropper, Landlord, Share + own, Sharecropping, Landless)
Food deficit household
Average no. of hungry months per year for food deficit households
Food sufficient households

Food surplus households
Average no. of months surplus harvest would be sufficient for, for the food surplus households
Percentage of households producing marketable surplus

5. Income distribution
No. of households in the groups Richest, Poorest, Most farmers
How many hungry months for Richest, Poorest, Most farmers
Size of land holding for Richest, Poorest, Most farmers
Surplus harvest sufficient for no. of months for Richest, Poorest and Most farmers
Income from supplementary sources (no. of hh's and Rs/yr) for Richest, Poorest, Most farmers
Type of housing for Richest, Poorest, Most farmers
Households with land holding size (no households)
<0.25 ha, 0.25-0.5 ha, 0.5-1ha, 1-2 ha, >2ha

6. Institutional structure
(Who does it and When)
Decision on water allocation
Implementation of water allocation
Decision on maintenance work
Implementation of maintenance work
Decision on size of water fees
Collection of water fees
Decision on size of fines
Collection of fines
Decision on size of penalties
Collection of penalties
How are the rules changed
Number of ordinary meeting of WUA per year
Average number of emergency meetings of WUA per year
What are the emergency meeting usually about

7. Changes in the individual farmers' behavior and in the institutional structure
Trend line for rule breaking
Trend line for the number of conflicts
Trend line for monitoring intensity
Trend line for the frequency of meetings within the system
Trend line for percentages of i) fees ii) penalties and iii) fines that are actually collected
Trend line for the changes in the rules of the system

Trend line for harvest sizes
Trend line for i) water availability and ii) water reliability

8. **Changes in the costs and benefits of using the irrigation system**
For major changes in the system, how has the following been affected (–, -, 0, +, ++) for Rich, Average and Poor, Head-, Middle- and Tail-end farmers:

Labor contribution needed
Material contribution needed
Cash contribution needed
Water availability
Water reliability
Harvest productivity
No of harvest per year
Time spent in meetings /discussions/ problem solving among users
Time spent in meetings /discussions/ problem solving among outsiders
No and/ or intensity of disputes among users
No and/ or intensity of disputes among outsiders
lThe marginal benefit of water
Were there any changes in cropping pattern or agricultural techniques used after the events

Case Study Appendix

In this Appendix, the case studies of five irrigation systems are presented. The focus is on institutional development, socio-economic development and cooperation. The presentation of each system ends with a very brief summary, on which the less interested reader can focus.

1 Baireni Kulo

Baireni Kulo is one of the systems constructed by Tharus a long time ago, in fact, it is believed to have been initiated by a Tharu Zamindar before 1965 B.S. (that is, almost 100 years ago). The area under cultivation was essentially the same as today, but there were only 15 households within the command area of the system. Due to the emerging availability of irrigation and the increase in the population, people have gradually converted an increasing amount of upland into irrigated land. The source of the system is Pampa Khola, an ephemeral stream ultimately draining into Rapti River. The flood plain of Rapti river has a history of floods, and the farmers reported the occurrence of floods in, for example, 2006, 2011, 2027 and 2050. There has been an acceleration in deforestation and floods after 2000, and Pampa Khola, which used to be a smaller stream, has been enlarged with each flood.

1.1 Institutional Development

Until 2027, there were only Tharus in the system, and all decisions pertaining to operation and management were made by the Zamindar, who had the final command. The role of the Zamindar was not only limited to irrigation management, he was also responsible for maintaining social order and norms in the society. He could punish and impose sanctions of any magnitude on indivduals disturbing the social order. In case of a dispute, the Zamindar had the authority to summon all individuals to a meeting, and whatever was decided used to be final. The rules were not written, but their enforcement was strict.

Before 2027, irrigation was limited to the monsoon season. The Zamindar together with the household heads used to decide upon the date for the annual canal desilting, and the Zamindar was also the person organising repairs whenever the brushwood intake in Pampa Khola was washed away by flash floods. The rule for labour contribution was that every able male member of every household had to help in the work. The only accepted excuses were illness and marriage or funeral ceremonies. If a person was absent from work without a valid reason, all the other users went to his house and collected the fine by force (in terms of goats, chicken or even rice). In case the defaulter refused to pay the fine, he would be socially boycotted. The users recalled one such incident in 2025, when a farmer who did not agree to pay the fine for absence at the time of maintenance was boycotted and had to move to another village. The authority of the Zamindar was such that very few dared break the rules. From 2027 and onwards, the fine for being absent from work has been set in cash instead of in kind, with the rate equal to the prevailing wage rate.[1]

Although the Zamindari system was abolished in 2022, the traditional way of decision making and the key role of the Zamindar still prevailed for a long period of time. However, with the settlement of hill migrants and the increase in their number after 2027, the Zamindar's command became less effective and the frequency of absentees at the time of annual repair and maintenance began to increase.

In 2038, a seven member executive committee of the WUA was constituted with the main purpose of supervising the physical construction and maintaining the budgetary records in connection with the FIWUD supported improvement of the irrigation system. After the completion of the construction work, the executive committee was supposed to take over the responsibility of operating and managing the system, but failed to do so. The Zamindar continued to have the key role in decision making until Nepal became a democracy in 2046. Then, his leadership was finally terminated.

In 2052, a formal WUA was constituted, and a formal institutional mechanism was developed for decision making regarding the operation and management of the system. The WUA functionaries were now the ones deciding on the dates for repair and maintenance. The need for labour had decreased and households now only had to contribute one person each for maintenance work. Despite this, the frequency of absentee users at the time of annual desilting showed a continuously increasing trend. Although the WUA has rules for the collection of fines and penalties, these only exist on paper. Since the constitution of the formal WUA in 2052, there have been no instances when fines or sanctions have actually been imposed on the defaulter.

1.2 Socio-Economic Development

In the early days, the land holdings were quite large and all households produced enough food to meet their needs. In 2027, there was a flood

[1] This seems to have been the standard fine in all systems and times. However, the monetary value of the fine for the same year often varies between systems, probably because of local labour markets.

that affected the command area and caused a food deficit for the first time. After that year, and particularly after 2038 when immigration and family separation started to take its toll on the size of land holdings, there has been an increase in the number of households with a food deficit. Although the successive rehabilitations and improvements of the system enhanced the availability and reliability of irrigation, they did not entail any large change in agricultural productivity. The farmers reported a reduction in the yield of most crops in the later years, primarily because of a degradation in soil fertility. This, in turn, was said to be caused by a lack of awareness of the importance of a balanced use of fertiliser when introducing high yielding varieties. Furthermore, there has been a decrease in the number of livestock and thus also in the supply of farmyard manure, while there has been an increase in the cost of chemical fertilizers. These factors have all contributed to a greater dependence on outside income sources. Many of the households that used to have large landholdings are now marginalised to an extent where they are dependent on wage earnings for their sustenance.

However, the extent of marginalisation is highly correlated with ethnic belonging. With the settlement of hill migrants, the Tharus who initially had large landholdings sold part of their land to the migrants. This, together with the larger families of the Tharus, made their landholdings progressively smaller.[2] The migrants, on the other hand, tended to buy land along the roadside and towards the head reach of the system and the value of their land has increased over time. Thus, the hill migrants grew wealthier while the Tharus gradually became poorer.

Considering outside income sources, there is a similar division among ethnic groups. The Tharus often gain their outside income from day labour, while most households with one or more individuals with an income from service, pension remittance or shops are migrants. The distribution of housing follows the same pattern.

1.3 Cooperation

Before 2027, there were virtually no instances of users attempting to make unauthorized use of water, taking water at other farmers' turn or damaging the canal structures. The reasons given were that the system was only operated during monsoon, when the supply in the system was

[2] The following example illustrates what a disastrous effect family separation might have on landholding sizes: One Tharu household that, until last year, had nine bigha of land now only has 16 Katha. The ancestral land has been divided among the nine male children and the parents (father and mother), making a total of 11 shares which gives 16 Katha for each separate household.

not scarce, and that the system was inhabited by Tharus only, who dared not challenge the command of the Zamindar.

With the increase in the number of migrants in the area, there was also an increase in the frequency of rule breaking and conflicts. As the Tharu households grew poorer, their influence and control over decision-making, power and politics decreased. The Zamindari system was mainly prevalent among the Tharus, and with their gradually decreasing dominance, the power of the Zamindar also decreased. However, until 2038, rule breaking and conflicts were still relatively rare.

An important difference between the Hill immigrants and the Tharu inhabitants was their view on what was a fair distribution of labour input. Among the Tharus, the prevailing norm was that all able men in the household, irrespective of the size of their land holding, must help in the work at the time of repair and maintenance. The hill migrants considered it fairer to let the labour contribution be based on the size of landholdings. This contributed to conflicts regarding the application of the rule in practice, and made the hill migrants unwilling to contribute labour. Between 2038 and 2040, the head end Hill migrants refused to contribute any labour at all for desilting of the canal. In response, the Tharus decided not to let the head-enders use the water. The conflict turned violent and the Tharus were beaten. Not until the Chief District Officer intervened was the conflict solved.

With the introduction of democracy in Nepal in 2046, the frequency of rule breaking and conflicts peaked as people became aligned to different political parties and political opinions, and differences started dominating the decision-making process. Furthermore, after the democratisation, the traditional governance through the Zamindar failed. With the formation of a formal WUA in 2052, the WUA functionaries laid out rules for fines and penalties. Although the conflicts have been somewhat reduced, these functionaries have not been able to control the frequency of rule breaking to any considerable extent.

1.4 Summary of Baireni Kulo

Initially, there was a one-man leadership, provided by the Zamindar. After 2027, his authority gradually decreased until it ended in 2046. In 2052, a formal WUA was constituted, although without much power to enforce its rules. In the early days, all households were food sufficient. Migration and family separation made the size of landholdings decrease over time, and the increase in crop productivity due to irrigation was not high enough to counter this effect, which has made people more dependent on outside income sources. There is a strong correlation between distribution of income and ethnic belonging, with Tharus in general being poorer and hill migrants richer. Initially, cooperation was good, but it deteriorated over time until 2046, when the situation began to improve slightly.

2 Baise Kulo

Baise Kulo is located in the Nawalparasi district. This irrigation system was first inhabited by hill migrants. In 2034, there were 15 households in the area, and between 2040 and 2044, more migrants moved in from the Baglung, Syangja and Parbat Districts. The area was surveyed in 2034, but settlers were not given land title until after 2040. As all users are hill migrants, mainly Brahmin, Chhetri, Magar or Gurung, it can be considered an ethnically quite homogeneous system. After 2044, the increase in the number of households has been due to family separation, resulting from population growth.

2.1 Institutional Development

Until 2040, the irrigation supply was unreliable and users were unorganized until 2040. Some maintenance work was carried out, but on an ad-hoc basis, and without rules for fining non-participants. With the improvements of the system in 2040, 2044 and 2048, the canal and area under irrigation gradually expanded and the number of users increased. This created a need for water allocation rules and in 2040, a nine-member executive committee of WUA was constituted. The committee occasionally developed a rotational schedule for water distribution, but did not effectively enforce it and, as a result, there were sometimes conflicts among users. The executive committee also started making decisions about annual repair and maintenance and developed rules for fining absent users. However, they had no mechanism for recording attendance or fining absentees, and the actual collection of fines was nominal until 2050.

In 2050, the users raised charges against the chairman and called a general assembly. A new chairman and executive committee were elected through secret ballot. The new executive committee drafted a constitution of the WUA which was registered at the District Administration Office. Although the other functionaries of the executive committee have been changing since 2050, the person elected chairman has retained this position ever since. The chairman, who is retired from the Indian army, has been the key actor in bringing reforms into the system.

The new WUA developed an elaborate set of rules for water distribution, labour contribution to maintenance, and punishments for those not following the rules. An interesting aspect of the rules is that for part of the regular repair and maintenance works, labour is mobilised on basis of irrigation time. Normally, the irrigation time during monsoon is 2 hours per bigha, but a user can increase or decrease the irrigation time, depending on his needs. The soil in the head reach of the system is less porous and one bigha of land can be irrigated in one hour. However, for emergency repairs and maintenance before the winter season, labour is mobilised on the basis of landholding size. The fine for being absent from work is kept equal to the daily wage, and the penalty for stealing water is set at NRs. 250.00 per turn of water stealing in day time and the double at night, when half of the penalty for water stealing goes to the individual discovering the rule breaking. The enforcement of the rules has become so strict that no user dares to break them. The role of the chairman has been crucial in this process.

2.2 Socio-Economic Development

Until 2034, none of the households were producing any surplus food. The number of food surplus households has increased slowly from 2040, but although the size of the surplus harvests increased between 2040 and 2048, it has been decreasing from 2050 and onwards. The increase came with the availability of irrigation, and the ensuing increase in cropping intensity. Later, multiple cropping caused a decrease in soil fertility, and the productivity of mustard and monsoon rice. At the same time, the process of family separation has decreased the land size of households over time. As a result, households previously producing enough food for the whole year, now suffer from a food deficit and more people have been forced into daily wage earnings. Some households have even had to sell land for survival in particularly hard times.

There is quite a large variety in the sources of cash income, partly because there is a number of cooperatives involved in various income generating activities. A few households grow vegetables or raise poultry, some have started bee keeping and since 2055, about 100 households raise dairy animals (cows or buffaloes).

Initially, there was a relative increase in the number of rich and average farmers, first because the newly constructed canal attracted rich farmers from the hilly areas and later, as a result of increased agricultural productivity. However, in 2058, the number of rich and average households had decreased, mainly due to family separation and the increasing cost of daily goods.

The main source of employment is temporary jobs in India. The majority of the households have land holdings of between 0.25 and 1 ha, and these farmers often get supplementary incomes as daily wage earners in various factories or other jobs in Nepal or India. The poorest households get their cash income mainly from road maintenance and stone mining work. A small number of people (mainly the households with a permanent house) work in the Indian army or receive a pension from having done so earlier, and some have temporary or permanent employment as school-teachers and/or in industries.

2.3 Cooperation

Until 2040, the instances of water stealing and conflicts were considerable, and unauthorized use of water was still common under the WUA formed in 2040. Not until the system was improved and rehabilitated in 2048, a new chairman was elected and a new WUA was formed in 2050 did the frequency of rule breaking and conflicts start to decrease. The new WUA combined an elaborate set of rules with an effective system for monitoring and enforcement. For example, it developed water distribution schedules and posted them for everyone to see. This made it possible for each user to know the exact time he was allotted for irrigation, the level of mutual monitoring among the users increased and helped reduce the intensity of the conflicts. The chairman who was elected in 2050 and who has remained chairman since, has played a key role in developing the new set of rules and ensuring that they are enforced.

2.4 Summary of Baise Kulo

Although there has been an informal WUA since 2040, the leadership was more or less ineffective until 2050. Cooperation was poor until 2050, that is, until after the physical and institutional improvement of the system. The chairman elected at that time has played a key role in developing an institutional setting that is now functioning well. Crop productivity increased until 2048, but has been decreasing since then, as has the size of land holdings. In combination, the two have made many households dependent on outside income sources, which they obtain from a large variety of sources. Income inequality increased in the early days of the system when rich migrants moved to the area.

3 Beltari Kulo

The Beltari Kulo irrigation system lies across the Narayani River from Narayanghat Bazar, which is a major market. Prior to 2029, the area was populated by Darai, Kumal, Danuwar and Bote, who were the original ethnic inhabitants. The area was upland and people were growing maize and millet in a limited area under shifting cultivation. The rest of the land was forested, uncleared and unsettled. The cultivation gradually became permanent after the land survey in connection with the government initiated resettlement program in 2029. Between 2021 and 2029, a large number of hill migrants came to settle in the area, and upon completion of the land survey, they were given land title and ownership. The settlers cleared the bush and forest land and brought it under cultivation. Until irrigation became available in 2036, the farmers could grow monsoon paddy only in about 12 to 15 bigha of land, despite the available water being adequate for irrigating 100 bigha. However, the source of the system is such that it is only possible to irrigate during the monsoon and winter seasons.

3.1 Institutional Development

The first attempt at getting irrigation was made in 2015, when a local Zamindar took the initiative to construct a canal with the intake in Jayashree Khola. Before the canal digging was completed, the Zamindar died and the construction was abandoned. In 2021, the users took a new initiative, this time under the leadership of an inhabitant of the area and an informal three-member construction committee. The work was contracted out to Nuniyas, specialists in earth work. While digging the canal, they came upon a large rock. As they were trying to move it, the rock slipped and killed two of the Nuniyas. The others fled, and once more, the work was abandoned. In 2029, the inhabitants decided to make another attempt and constituted a fifteen-member informal WUA under the leadership of the son of the local Zamindar who took the first initiative to get irrigation. While the construction work was still going on, a heavy flood in Jayashree Khola damaged the intake and as a result, the work was abandoned for the third time.

The WUA of 2029 was reconstituted in 2034, when the users took yet another initiative to make the system functional. This time, the WUA made a detailed cost estimate and obtained some financial support from the local authorities. The work was finally completed and the system started to function in 2036, although too late in the season to be of much use in that year. In 2037, eleven branch canals were constructed and in each branch canal, a branch commander, selected from among the users, was made responsible for water allocation and dispute settlement.

The responsibility of the WUA constituted in 2034 was limited to system construction and resource mobilisation and became defunct when the construction was completed. From 2036 to 2039, the day to day operation and the management of the system were carried out by the branch commanders but in 2039, a new WUA was constituted and took over the management responsibility. Most of the functionaries of this WUA still hold their positions. In 2055, the system was adopted for rehabilitation and improvement support in the Nepal Irrigation Sector Project (NISP), and the WUA was formalised and registered with the District Water Resources Committee.

At present, there is an elaborate set of rules and a well developed institutional structure to deal with water allocation, maintenance and rule breaking. Water allocation takes place at three levels in the system, first into two major branch canals, then into sub-branch canals off-taking from the two branch canals and finally, into the individual farmers' fields. One elected representative from each of the two branch canals is responsible for the distribution into the branch and sub-branch canals. Each sub-branch canal has a branch commander responsible for working out a schedule of irrigation turns when the water supply is low. At the time of paddy transplanting, the branch commanders and the representative concerned meet at least twice daily to assess the progress in transplanting and make adjustments in the irrigation schedule.

The responsibility for the maintenance work is distributed in a similar way. The executive committee meeting decides on the date and time of the annual desilting and allocates the work between the two branch canals. The branch commanders allocate the work on the branch and sub-branch canals among the users of their branch. They are also responsible for the collection of the repair and maintenance fees and for depositing the collected amount with the treasurer in the main executive committee. Decisions regarding physical construction work are taken in the executive committee after its functionaries have made their annual joint inspection of the whole system.

3.2 Socio-Economic Development

The area has a relatively recent history of settlement, and both settlement and land distribution were initiated and supported by the government. The majority of households own less than one hectare of land and since most farmers are small holders, they are essentially owner croppers with only a few households leasing out land for sharecropping.

With the land survey in 2029, the government distributed a fixed amount of land to the settlers and removed the opportunity to bring forest land under cultivation. Until 2044, all households were food deficient and before 2029, they only produced enough food for three months per year. With the availability of irrigation, food sufficiency increased to four months in 2036 and six months in 2049. Over time, the total number of food deficient households increased, however; because of immigration until 2036, and later due to land fragmentation. In 2044, the richer households produced a surplus for the first time, equivalent to about three months' consumption, but in 2058, this had decreased to two months worth.

The households in the system have traditionally been engaged in dairy cattle raising. In 2055, a dairy cooperative was established and at present, about 240 households produce and sell milk. Paddy straw is sold as livestock feed and raw material to a nearby paper mill. There has been an expansion in the poultry business and an increased number of poultry feed mills, which has led to a higher demand for maize. The people with an income from service are mostly employed by the government sector or by non-governmental organisations, and the vast majority of the daily wage earners work as porters in the town of Narayanghat.

3.3 Cooperation

The operation of the system constructed in 2036 was unreliable because of the temporary nature of the intake and canal and the absence of branch canals. For a few years after the construction of the system, there were conflicts regarding water distribution. With the construction of the two major branch canals and the sub-branch canals, the irrigated area expanded and the farmers' access to irrigation increased, which helped reduce the intensity of disputes among the farmers.

Irrigation is extremely valuable to the farmers, and there is a high degree of interpersonal monitoring which makes it very difficult for a farmer to steal water or irrigate on someone else's turn. The farmer who is next in turn keeps an eye on the farmer who is presently irrigating, to ensure that he can start irrigating at the scheduled time. This, rather than the rules for imposing cash penalty on those attempting to break rules, was given as the main reason for the low frequency of rule breaking.

The frequency of conflicts regarding water use has also been kept at a low level, once more because all farmers value irrigation water extremely highly and have a great concern for a conflict free operation of the system. Furthermore, the WUA's institutional arrangements are aimed at keeping conflicts regarding water use to a minimum.

In connection with the reinstatement of democracy, there was a slight increase in both rule breaking and conflicts. However, with the improvement in irrigation reliability after the rehabilitation and the improvement of the system in 2055, the intensity of disputes among users decreased once more.

3.4 Summary Beltari Kulo

In this system, there seems to have been no key person, except in the initiatives taken to construct the system. Thereafter, the WUA has been responsible for managing the irrigation system. On average, the households have fairly small land holdings. Over time, the number of food deficient households has increased, but the food sufficiency of individual households have increased. The distribution of income has been fairly constant over time. Initially, there were some conflicts regarding water distribution, but this decreased with the improvement of the physical and institutional structures. At the time of democratisation, conflicts and rule breaking increased somewhat, but then decreased once more.

4 Jayashree Kulo

Before 2024, a very small part of Jayashree Kulo's present command area was cultivated, the rest was covered in forest or bushes. The land was registered in the name of two landlords, but cultivated by tenants. Since both landlords possessed large land areas and the major part of the area was uncultivated, they encouraged new settlers to move in and bring the land under cultivation. In 2017, the first migrants, 16 Brahmin households, moved into the area. In 2027, the construction of the Narayanghat-Butwal section of the East-West Highway started, which attracted migrants from all over the country, but particularly from the adjoining districts of Tanahun and Baglung. Gaindakot, about one kilometer from the system area, started growing into a small township. The construction of a bridge over the Narayani river in 2041 connected Gaindakot with Narayanghat, the major town and market center in Chitwan District. The construction of the road and bridge contributed to a large increase in the population of both Narayanghat and Gaindakot.

4.1 Institutional Development

In Jayashree, there has been an informal WUA since the very initiation of the irrigation system in 2023, and the present chairman of the WUA has held the post since he was first elected in 2033. The chairman has been putting much time and energy into the irrigation system to ensure a smooth operation and an equitable distribution of water. He has attempted to give up the responsibility several times, but each time the users, who find him indispensable, have persuaded him to continue as chairman.

Until 2042, the available supply in the canal was seriously constrained even during monsoon, and water was allocated on a rotational basis, both between and within the branch canals. From 2042, there are four different ways of water allocation altogether, one each for the time of rice transplanting, the rest of the monsoon, the winter and the spring seasons. In the transplanting period, the chairman spends a minimum of four to five hours a day in assessing the progress of rice transplanting in the branch canals and monitoring the irrigation delivery. In the monsoon, the WUA and branch leaders are in charge of drawing up the irrigation schedule. In the winter and spring seasons, the farmers communicate their need for water directly to the chairman, who then decides on the time slots for irrigation to different farmers, and monitors the irrigation delivery in person to avoid conflicts among the farmers.

The executive committee of the WUA has the overall responsibility for the operation and maintenance of the system and the related decision making. At the branch canal level, a branch leader is nominated among the users, who works as a leader and representative of the users within the branch. The branch leader has a crucial role in the allocation of irrigation and the execution of repair and maintenance. The branch leaders are generally invited to the meetings of the executive committee, but need not be members.

The present WUA was constituted and registered in 2050 in connection with an application for external support. Among other things, penalties and fines were made payable in cash but so far, no cash penalty has been collected. One reason is that the volume and reliability of the irrigation supply increased after the rehabilitation support in 2054. Until 2054, the general assembly of users was called once a year but after 2054, it has been organised less regularly, and not once after 2056. During this period, the executive committee of WUA has been forming new rules or making changes in the existing set of rules on its own. The thirteen functionaries and members of the existing executive committee were elected in 2050 and have remained the same.

4.2 Socio-Economic Development

Before the initiation of the irrigation system in 2024, all except a few rich households were food deficient. However, the average landholding size is quite large and together with the availability of irrigation, this has resulted in a significant rise in the productivity of monsoon paddy, for example. Over time, the number of food deficient households decreased and in 2033, only the poorest households were still food deficient. Furthermore, between 2023 and 2058, the number of food deficit months decreased from six to three.

There has also been a reduction in the productivity of several crops.

Mustard, originally an important cash crop, gradually lost in productivity and was replaced by wheat. By 2054, wheat had also lost in productivity, as well as market price and, at present, vegetables, buckwheat and green peas are the main cash crops.

The landholding sizes of all economic categories have decreased over time, but the rate of land fragmentation has been higher among poorer farmers. However, since most households still have relatively large land holdings and small holding households carry out share-cropping on the lands of large holding households, very few households depend on wage earning as labourers. With the increasing awareness of the importance of educating children and the establishment of schools and colleges in the vicinity, both the number of educated people and the number of people engaged in service occupations have increased after 2050.

The increased wealth is also indicated by the change in the type of housing over time. Until 2042, most houses in the area were temporary. The first permanent house was built in 2042 and today, there are only a few temporary houses left, most of these belonging to small holding households of the Kumal, Kami, Sarki and Praja ethnic groups.

4.3 Cooperation

In general, the extent of rule breaking in the system has been low. Prior to 2042, when the availability and reliability of irrigation were very low, some users violated the rules and made attempts at unauthorized use of water. These cases were isolated and occurred very rarely. With the improvements of the system carried out in 2042, the reliability of water supply increased and the frequency of rule breaking decreased even further. After 2054, rule breaking has virtually been reduced to nil. The main reasons for the reduction in the number of conflicts after 2042 and 2054, respectively, were the improvement of the physical and structural characteristics of the system and the provision of branch leaders in the branch canals. The chairman of the executive committee, who has held this post since 2033, has also been playing a very important role in maintaining the events of rule breaking and conflicts at a very low level. He spends a great deal of time monitoring the system and has earned the faith and recognition of the users.

4.4 Summary of Jayashree Kulo

There has been a WUA since the initial construction of the system, and the same person has been chairman since 2033. The chairman spends a great deal of time on managing the system and is perceived as indispensable by the users. The income level of the users is quite high and has been increasing over time. The landholding sizes have been and still are fairly large and agricultural productivity has been increasing. The distribution of land has become slightly more unequal, as the rate of land fragmentation has been higher among poorer households. Cooperation has been kept at a fairly high level from the beginning, but has improved over time.

5 Shivpur Martal Kulo

In 2021, people from the adjoining hill districts of Dhading, Makwanpur and Sindhupalchowk began to settle in the area. Previously, there had been scattered settlements of Danuwars, but these had moved out. In 2026, the government made a land survey of the area. The cleared and cultivated land, about one fourth of today's command area, was registered in the name of the cultivators, each receiving two bigha of land. The main inflow of migrants started after the land survey and when the plans for the construction of the Narayanghat-Hetauda section of the east-west highway became known. The resettlement of flood victims in 2027 also contributed to the inflow of people. When the construction of the irrigation system was completed in 2037, the area received another large inflow of migrants. After 2049, there has been little immigration and the subsequent increase in the number of households is primarily due to family separation.

5.1 Institutional Development

The present chairman of the WUA has been the leader of the irrigation system since its initiation. Until the completion of the canal and the beginning of irrigation in 2037, it was more or less a one-man show. In 2037, a seven-member executive committee was formed for the day to day operation and management of the system. In 2049, a new constitution of the WUA was drafted and was formally registered. Between 2037 and 2049, the functionaries and members of the executive committee whose performance was unsatisfactory were regularly replaced by the general assembly, but since 2049, they have all remained the same.

In the initial construction of the system and for some time thereafter, the poor farmers from the head reach of the system provided the leadership, while the middle reach farmers played a smaller role in leadership and decision making. Most functionaries in the executive committee of the WUA belong to the average and poor farmers from the head and middle reach of the system, while the rich farmers from the tail reach have no involvement in decision making.

Prior to the rehabilitation and improvement of the system under ERIP in 2053, the farmers had to rotate water among and within the three branch canals, even during monsoon. The allocation of irrigation among users was the responsibility of the chairman and secretary, and required daily involvement during the monsoon season. The chairman and secretary were also responsible for allocating the repair and maintenance work and keeping records of the users' attendance.

In 2046, the WUA developed a rule to impose cash penalty, doubled for successive offenses, on users attempting to make unauthorized use of water. However, the implementation of the rule was only effective until 2049, and from 2052, the WUA has not been able to collect any penalties at all, for two reasons, according to the farmers. First, the temptation to make unauthorized use of water decreased with the increase in water availability and reliability. Second, somehow the farmers got the impression that since the government supported the rehabilitation of the system, it was also taking over the responsibility for running it. Therefore the farmers should not have to pay penalties.

Until 2056, the general assembly of users was organised regularly. After 2056, the executive committee of the WUA has attempted to call the general assembly several times but due to a lack of required quorum, no formal discussions could be held. All functionaries of the executive committee have completed their tenure and because of the situation in the system, they all want to be relieved of their responsibilities. However, in the absence of a general assembly, it has not been possible to replace them.

5.2 Socio-Economic Development

Prior to 2049, the irrigation system only covered the head and middle reach of today's command area. Initially, all users were poor and until 2037, they were all were food deficient. Over time, the number of food deficient households has been decreasing, with the major change in 2047 when the farmers started using high yielding crop varieties. At present, the poorest households, owning less than 5 katha of land, only produce enough food for six months. Only the rich households produce a surplus of food, and this only from 2042. The households with medium-size landholdings became food sufficient with the availability of irrigation after ERIP's support.

Rich and average farmers live in the tail reach and joined the system after or in connection with ERIP's rehabilitation and improvement support. Over time, the landholding size of all households has decreased, but the rate of land fragmentation has been higher among poor households. Furthermore, the richer households have benefitted more than the poor from irrigation. There is also a difference between rich and poor farmers in terms of how they supply their share of labour in construction, repair and maintenance works. While poor farmers contribute labour themselves, the average and rich farmers prefer to pay cash for their share of labour.

5.3 Cooperation

Prior to 2042, the users cooperated well in sharing the limited irrigation supply of water and the instances of rule breaking were limited to some isolated events of farmers attempting to take water on other farmers' turns.

The frequency of rule breaking and conflicts among users peaked between 2049 and 2053. It began increasing after the reinstatement of democracy in 2046, when there was an increasing political alignment and differences in opinion among the users. This also coincided with a period of changes in the organisational structure of the irrigation system, in connection with the rehabilitation and improvement works. Since ERIP was a government initiated irrigation rehabilitation and development project, users developed a feeling that the government would henceforth be responsible for everything in the system. Although there were instances of unauthorised use of irrigation, rule breaking mainly took the form of refusals to contribute labour to the repair and maintenance work. Furthermore, the tail end farmers, who were the richer ones, started influencing the decision-making process but stopped contributing labour in the regular repair and maintenance of the system.

The situation has now deteriorated to a point where the functionaries of the executive committee, who provided the leadership in the initiation of the irrigation system and in seeking external support for the rehabilitation and improvement, are no longer willing to continue their task.

5.4 Summary of Shivpur Martal Kulo

The present chairman has been the leader since the first initiative to get irrigation was taken, first alone and then, after the system became functional, together with a WUA. Over time, the number of food deficient households has decreased. Today, the poorest produce enough food for six months, and only the richest households produce a surplus. The increased agricultural productivity has decreased the poor households' dependence on wage earnings. Cooperation has been decreasing over time, except for a slight improvement in the last few years. The government-supported improvement of the system in 2049 has made the WUA less effective, as farmers believe that the government is now responsible for the running of the system. In the last few years, none of the functionaries of the executive committee of the WUA have wanted to remain in their positions since the WUA has not been functioning, but they have yet to be replaced.

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