Cooperation or Conflict in Common Pools*

Ingela Ternström†

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Abstract

Many of the world's common pool resources are located in poor countries, where consumption levels may be low enough to adversely affect 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 lower probability of cooperative management of common pool resources than groups with adequate consumption levels. However, users that are only moderately poor have the greatest chance for cooperation. For this group, if resource productivity varies, 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 resource, developing countries, dynamic game, irrigation, natural resource, non-linear utility.

JEL Classification: C72, O13, Q15, Q25

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†Department of Economics, Stockholm School of Economics, P.O. Box 6501, S-113 83 Stockholm, Sweden. E-mail: Ingela.Ternstrom@hhs.se.

1 Introduction

A common pool resource (CPR) is a resource that has 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 CPR's, 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 in the literature is an explicit consideration of the socioeconomic status of the people managing these resources.

Non-cooperative game theory has long been used to analyse the commons problem. The infinitely repeated prisoner's dilemma is usually the preferred parable, since it captures in a simple way how community incentives can keep in check short-run incentives to take more than one's share of the resource. This paper, too, uses non-cooperative game theory but also brings into the analysis the fact that in the third world the 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. 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 actions of the users decide the level of output from the CPR. 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 as when it is small.

This paper predicts a non-monotonic relationship between the size of the resource and the chances for 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 the person's 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 for 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 the exogenous factor deciding the state of the resource is varying, seasonally or stochastically, 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. We also find that cooperating some of the time can be a both possible and welfare improving alternative when cooperation all of the time is impossible. When we combine these results, the model is strongly supported by the empirical finding that in functioning CPR's the relatively less productive period is the greatest challenge to cooperation.

Baland and Platteau (1996, Ch. 12) give a summary of the characteristics that are 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 the users should be highly dependent on the CPR. There are also many empirical examples that relate breakdown of cooperation to resource scarcity. Ostrom (1990), regarding irrigation systems, 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] Baland and Platteau (1996), regarding irrigation systems in India, 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 give examples of such incidences.[5]

In the literature there are also examples of very old CPR's that cease to function altogether with the disappearance of an outside income source. Baland and Platteau (1996, pp. 266–) tell the story of fishermen in Gahavälla, traditionally living off a combination of CPR fishery and wage earnings from day labour. When the wage earnings ceased due to a reduction of economic opportunities in agriculture, it became more difficult to sustain cooperation in the fishery, 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 is evident when considering the degree of dependence on local resources in developing countries, as discussed in for example Dasgupta and Mäler (1997).

[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. Breakdown of cooperation was avoided by increasing fines.

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 related in some ways to the problem of price wars in oligopolies, see for example Green and Porter (1984) and Rotemberg and Saloner (1986). While the former assumes imperfect information, Rotemberg and Saloner makes the same assumption as we do here, in that the 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. Our model predicts deviations in bad periods, for exactly the same reason.

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

2 The Model

Throughout the paper, our 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, we assume that there are only two agents and that they are identical in all aspects. 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 by the farmers. The benefit of the rain can be enhanced by the use of the irrigation system. By how much the use of the irrigation system benefits the farmers depends on whether the farmers cooperate in the use of the irrigation system or not. The farmers decide whether to cooperate or not by comparing the utility gained by taking the 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 for this: 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

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

productivity that affects the harvest size in a non-linear fashion, and; the utility gained from different levels of consumption may not be linear. If we have multiple sources of non-linearity, their combined effect depends on the relative location of these non-linearities, they may either join forces or have a neutralising effect on each other.

Given that we are examining poor agents, we choose here 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 probability of staying in good health as presented by Dasgupta (1993, ch.14). We 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]

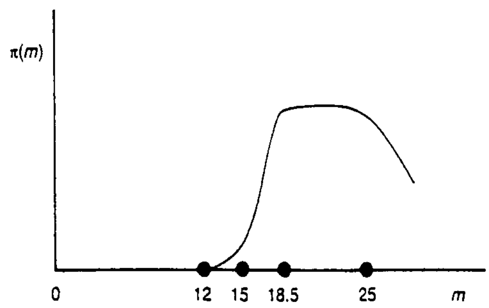

Figure 1: One minus the probability of health breakdown, p(m), as a function of body mass index, m. Source: Dasgupta (1993) p. 416.

The causes for decreasing marginal health-benefit from food above certain levels are probably well known to all, but the increasing marginal health-benefit may need some explanation. The reason is that the human body uses energy to extract energy from the food put into it. If the food input is too low, there is not energy enough 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 decrease the amount of energy that 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), in 1990-92 about 20 percent of the population in the developing countries had inadequate access to food, implying a BMI of 18.5 or less.[8] These 20 percent will be measuring utility on the non-concave part of the utility function. Assuming

[7]See also e.g. Weir, 1995, for an estimate and 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

that it is the poorer rather than the richer parts of the population that depend on CPR's for their livelihood, the percentage gets even higher. Based on the information in tables 14.2 and 14.3 in Dasgupta (1993), we conclude that among the 42 least developed countries in 1993/94, 10 countries had an average BMI between 12 and 15, 20 had an average BMI of 15 to 18.5, and 12 had an average BMI above 18.5.

The figures above make it abundantly clear that we must take the particularities of poor people into account when modelling CPR's in developing countries. To do this, we assume that health is an important component in utility. We can thus 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, comes mainly from the crops grown on the farmer's field, 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. We assume that the utility function can be characterised as

$$U\left(\alpha\pi_{a_1,a_2}\right) = \begin{cases} f\left(\alpha\pi_{a_1,a_2}\right) \ if \ \alpha\pi_{a_1,a_2} < \text{MMI}; \\ g\left(\alpha\pi_{a_1,a_2}\right) \ if \ \alpha\pi_{a_1,a_2} \geq \text{MMI}, \end{cases} \tag{1}$$

where both are increasing but $f(\cdot)$ is non-concave and $g(\cdot)$ non-convex.[10,11] The inflexion point is referred to as MMI, the point of maximum marginal impact. $\alpha\pi_{a_1,a_2}$ represents the size of the harvest, expressed in BMI-equivalents (α, π and a are defined in the next section). In the numerical examples we use

$$U\left(\alpha\pi_{a_1,a_2}\right) = 100 \cdot \left\{1 + \frac{1}{1+\alpha\pi_{a_1,a_2}} \cdot \exp\left[-\gamma\left(\alpha\pi_{a_1,a_2} - \text{MMI}\right)\right]\right\}^{-1} \tag{2}$$

with MMI $= 16.5$, and $\gamma = 1.25$. The figure below shows the resulting utility function. We have assumed that the y-axis in Figure 1 is measured in percentages, and utility is assumed to be measured on the same scale. The x-axis shows the

the population was 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 children under the age of five suffered from malnutrition. Based on Table 6, World Development Report 1996.

[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 body's basic functions.

[10] Note that we assume implicitly that people will stop eating before it has a negative effect on their health.

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

BMI-equivalent of the harvest when cooperating, for different levels of rainfall.

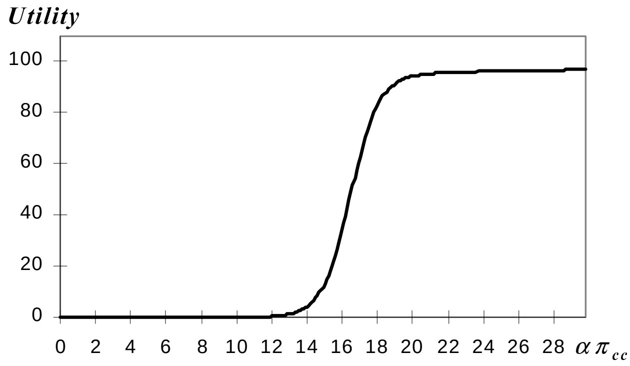

Figure 2: The utility function of equation (2).

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 cooperate and d deviate. To focus attention, the relative size of the harvests for different combinations of actions, π_{a_1,a_2}, is kept constant throughout the paper. This 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 that the farmers get when cooperating relative to the size of their harvests when not cooperating is unaffected. What we then have is a CPR game where the absolute sizes of the payoffs vary (with the level of rainfall) but the relative size of the payoffs remains the same. We can thus express farmer 1's harvest as $\alpha\pi_{a_1,a_2}$ with α being the amount of water. By assumption,

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

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

$$2\pi_{c,c} > \pi_{d,c} + \pi_{c,d}. \tag{4}$$

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

2.3 The Repeated Game

In the repeated game, we assume discrete time, t, and infinite horizon. The size of the harvest in a certain time period decides the level of the farmer's utility during that same period. We assume that the farmers have identical discount factors, δ.[12]

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 that generates 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 every period until they for the first time notice that someone has deviated, and thereafter shift to playing "deviate" forever) is optimal in this sense. If such trigger strategies can not sustain cooperation, neither can any other strategies. Otherwise, cooperation is a possible equilibrium outcome. The discounted utility of behaving cooperatively, when all players do so, will be

$$\sum_{t=0}^{\infty} \delta^t U\left(\alpha \pi_{c,c}\right), \tag{5}$$

and the discounted utility of deviating is

$$U\left(\alpha \pi_{d,c}\right) + \sum_{t=1}^{\infty} \delta^t U\left(\alpha \pi_{d,d}\right). \tag{6}$$

To test whether the trigger strategy can sustain cooperation, it suffices to check whether it will be beneficial for the agents to deviate from the trigger strategy in a single period. Thus, for cooperation to be a subgame perfect equilibrium, expression (5) must be equal to or greater than expression (6). Thus cooperation can be sustained for all discount factor above the critical level,

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

What we are 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 be the critical discount factor at which a certain set of material payoffs can be supported as a subgame-perfect equilibrium outcome. The intuition behind this result is that an agent with a strictly concave utility function has a lower marginal valuation of the increased payoff gained by deviating and a higher marginal valuation of the decreased payoff when punished for it, than has an agent with a linear utility function.[13] Applying this argument to our S-shaped model, the implication should be that with the same relative harvest sizes, the utility gained

[12] We also assume that the farmers' discount factors are independent of their consumption level.

[13] Note, however, that while Spagnolo keeps the material payoffs constant, we have to take into consideration that as α increases both the size and the spread of the material payoffs increase.

by deviating relative to the utility lost when punished for doing so 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 segment than on the concave segment. More generally, we have the following result:

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

Proof. Solve for $U(\alpha\pi_{c,c})$ in (7) to get the following expression,

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

This is equivalent to the definition of the certainty equivalent of a lottery with the 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,[14] that is,

$$RP = \delta^* U(\alpha\pi_{d,d}) + (1-\delta^*) U(\alpha\pi_{d,c}) - U(\alpha\pi_{c,c}). \tag{9}$$

Define the convexity measure $U''\left(\alpha\pi_{a_i,a_j}\right)/U'\left(\alpha\pi_{a_i,a_j}\right)$ (i.e. the negative of the Arrow-Pratt measure of risk aversion). Since risk-aversion and concavity of the expected utility function are equivalent measures,[15] we know that as the concavity of the utility function increases, *RP* must increase. From (9) 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 happens in the intermediate segment, where $\text{MMI}/\pi_{d,c} < \alpha < \text{MMI}/\pi_{d,d}$, we return to equation (8). First, as the payoff from deviating increases above MMI, the growth rate of this payoff will be slowing down. To keep (8) satisfied, this must be countered by a decreasing critical discount factor. When α increases further, so that $\alpha\pi_{c,c} >\text{MMI}$, the cooperative payoff too starts 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 the shape of

[14] See e.g. Kreps (1990) p.84.
[15] See e.g. Varian (1992) p.178.

critical discount factor.

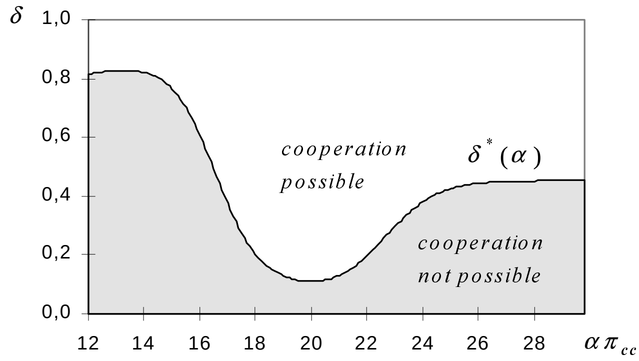

Figure 3: The critical discount factor when $\pi_{d,c} = 1.1\pi_{c,c}$ *and* $\pi_{d,d} = 0.9\pi_{c,c}$.

3 Empirical Implications

The results of the above analysis imply that if utility is linear, the amount of water available is irrelevant to the probability of cooperation. However, if utility is not linear, the curvature of the utility function is of crucial importance to the chances of cooperative management of the CPR. 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 having it reduced instead.

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.

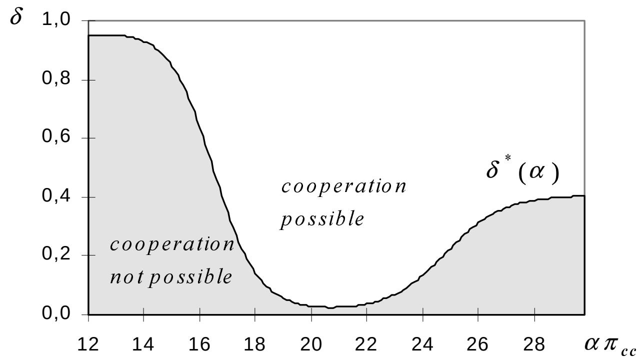

Figure 4: The critical discount factor with large difference between relative payoffs, $\pi_{d,c} = 1.2\pi_{c,c}$ *and* $\pi_{d,d} = 0.8\pi_{c,c}$.

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

How well do these results fit with the empirical evidence? One of Ostrom's (1990) main characteristics of successful CPR's was that the users should have a high degree of dependence on the resource. Here, we have assumed that the CPR is their only source of food, which in itself makes them dependent on it. From the above analysis we find that given this, the chances for cooperation are highest when the users have the most to lose from not cooperating. We can thus conclude that so far, the model gives realistic predictions.

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 the wage from day labour. Utility will now be a function of the sum of the income from the two sources. Let the additional income source be the one that depends 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 multiplicative effect.[16] By performing the same analysis as above, we can analyse how different sizes of the complementary income affects the cooperative efforts of the farmers. The critical discount factor will now look as follows, with the subscript *add* for additive,

$$\delta^*_{add}(\alpha) = \frac{U(\alpha + \pi_{d,c}) - U(\alpha + \pi_{c,c})}{U(\alpha + \pi_{d,c}) - U(\alpha + \pi_{d,d})}. \tag{10}$$

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

[16] This also implies relaxing the assumption of constant relative payoffs in favor of constant absolute difference between payoffs.

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

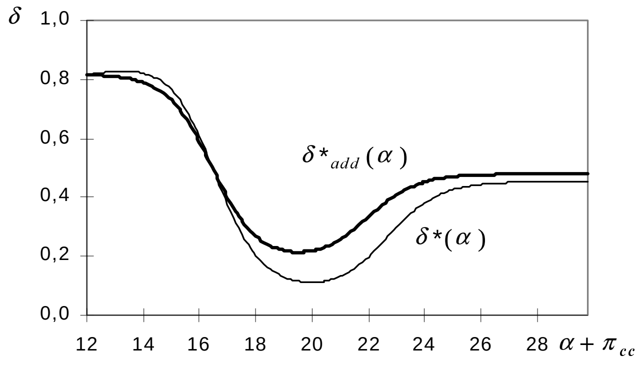

Figure 5: The critical discount factor with a complementary income source when the return from the CPR is too small to survive on; $\pi_{c,c} = 12$, $\pi_{d,c} = 1.1\pi_{c,c}$ *and* $\pi_{d,d} = 0.9\pi_{c,c}$.

The implication is that the success of cooperative management of a CPR also depends on the size of 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 either direction of the size of the complementary income. By varying the size of the cooperative payoff, we can study the effects of different degrees of dependence on the resource. As $\pi_{c,c}$ decreases, the critical discount factor becomes flatter. This implies that the sensitivity to changes in the additional income source decreases, 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 CPR fishery had developed and improved over a long time, from which we may suspect that the system was operating on a scale where cooperation was easy to sustain. The disappearance of their complementary source of income implied a leftward move along the utility curve and an increased critical discount factor. Consideration for this kind of effects should be given when choosing location for aid projects, both when the project itself requires cooperative management and when there are pre-existing CPR's.

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 convex utility would increase their total utility by making their consumption as uneven as possible. That way, 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 that is close to dying from starvation would voluntarily give up any of his consumption today for use in a future period, since that future period may never come. Thus, the assumption of time separable utility becomes particularly cumbersome in the context of saving and convex utility, and we shall refrain from using our model to analyse this case. As far as credits are concerned, we 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 wanted to.

Thus, we focus here on the concave part of the utility function. With concave utility, being able to reallocate the consumption of some of the extra harvest gained when deviating to one or more punishment periods 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 a hindrance to cooperation will storing 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

$$\begin{aligned} & U\left[\alpha\pi_{d,c} - (1-s)\left(\alpha\pi_{d,c} - \alpha\pi_{d,d}\right)\right] + \delta U\left[\alpha\pi_{d,d} + rs\left(\alpha\pi_{d,c} - \alpha\pi_{d,d}\right)\right] \\ & > U\left(\alpha\pi_{d,c}\right) + \delta U\left(\alpha\pi_{d,d}\right). \end{aligned} \tag{11}$$

The larger is r and the more concave is the utility function (i.e. the larger is the difference in marginal utilities), the larger is the left hand side of equation (11), and the more of a threat will storing be to cooperation.

If on top of a perfect storage method we introduce credit markets, thus adding the possibility to earn interest on the saved amount, the effect is the same as if the fraction remained after storing would be larger than one ($r > 1$). Furthermore, credit institutions would make it possible to spread the gains from deviating over more than two periods, further increasing the marginal utility of deviating.[17]

The effect of introducing goods markets may be illustrated as an increase in the marginal benefit from deviating because there is a market on which the extra 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, i.e. making utility move more quickly towards its maximum.[18] In the figure below (where we have increased γ in equation (2) to 1.50 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. When Jodha (1988) suggests that the introduction of a nearby marketplace is harmful to the cooperative management of a CPR due to a change in attitudes, what really matters is perhaps the possibility to change

[17] For a more thorough analysis see e.g. Spagnolo, 1998.

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

the composition of consumption and thereby get a higher marginal utility from deviating. However, as the figure below also shows, at lower consumption levels the effect may be the opposite.

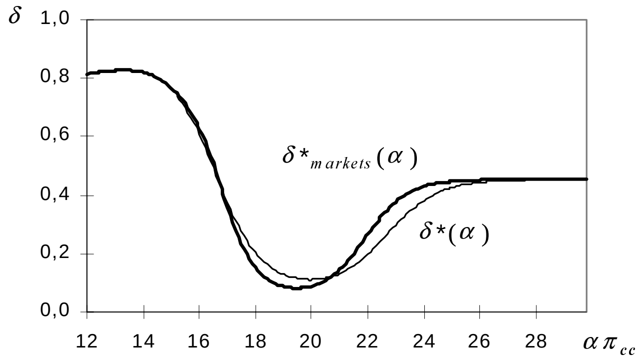

Figure 6: The critical discount factor with access to markets, when $\pi_{d,c} = 1.1\pi_{c,c}$, $\pi_{d,d} = 0.9\pi_{c,c}$.

4 Variations in the State of the Resource

In this section we extend the base-line model to analyse the effect on cooperation of variations in the amount of rainfall. We focus here on stochastic variations, while the analysis of seasonal variations is referred to Appendix A. The main difference lies in the calculation of future harvest sizes, where the probability in the stochastic case, and the timing in the seasonal case, affects the outcome. When we let the relative probability of the rainfall levels in the stochastic case equal the relative length of the seasons in the seasonal case, the results are very similar. Note that the game is no longer a repeated game, since the state of the resource varies. Thus the trigger strategy used so far may no longer be the optimal choice of strategy. The extension in Section 5 shows a strategy that may improve the outcome.

4.1 Stochastic Variations

Suppose that weather is variable and somewhat unpredictable. The farmers know the possible rainfall levels and their likelihood, but do not know what the actual level of rainfall will be until each period begins. We thus continue to assume that the farmers have full information about the level of rainfall in the present period, but assume now that future rainfall levels are stochastic. To simplify the analysis we assume *i.i.d.* shocks and only two possible rainfall levels, wet (α_w) or dry (α_d), with $\alpha_w \geq \alpha_d$ always.[19]

[19] In reality, there will be many possible rainfall levels, and not just two as assumed here. This should not affect the analysis in any major way, as the only difference in the equation for

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[20] from a certain combination of actions in any future period as

$$E_\tau \left[U\left(\alpha_\tau \pi_{a_1,a_2}\right)\right] = p_w U\left(\alpha_w \pi_{a_1,a_2}\right) + \left(1 - p_w\right) U\left(\alpha_d \pi_{a_1,a_2}\right). \tag{12}$$

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

$$U\left(\alpha_w \pi_{c,c}\right) + \sum_{t=1}^{\infty} \delta^t E_\tau \left[U\left(\alpha_\tau \pi_{c,c}\right)\right] = U\left(\alpha_w \pi_{d,c}\right) + \sum_{t=1}^{\infty} \delta^t E_\tau \left[U\left(\alpha_\tau \pi_{d,d}\right)\right], \tag{13}$$

and solve for the critical discount factor,

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

The critical discount factor of a dry period is correspondingly,

$$\delta^*_{stoch}\left(\alpha_d\right) = \frac{U\left(\alpha_d \pi_{d,c}\right) - U\left(\alpha_d \pi_{c,c}\right)}{U\left(\alpha_d \pi_{d,c}\right) - U\left(\alpha_d \pi_{c,c}\right) + E_\tau \left[U\left(\alpha_\tau \pi_{c,c}\right)\right] - E_\tau \left[U\left(\alpha_\tau \pi_{d,d}\right)\right]}. \tag{15}$$

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 for doing so. Since the expected punishment is the same for both outcomes, it will take a higher discount factor to sustain cooperation in the outcome that gives the largest benefit from deviating. Thus, we can state the following:

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

Proof. Assume that $\delta^*_{stoch}\left(\alpha_w\right) < \delta^*_{stoch}\left(\alpha_d\right)$. Substituting from equations (14) and (15) and simplifying yields

$$U\left(\alpha_w \pi_{d,c}\right) - U\left(\alpha_w \pi_{c,c}\right) < U\left(\alpha_d \pi_{d,c}\right) - U\left(\alpha_d \pi_{c,c}\right). \tag{16}$$

■

the critical discount factor will be that the expected loss from deviating consists of more terms.

[20] Note that we 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 having more rain in the wet period will always work in the direction of making it more difficult to cooperate. 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 period 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 dryer year.

Combining this result with the main result of the analysis in Section 3, we can conclude that when the chances for 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 CPR's, deviations occur mainly in the less productive period.

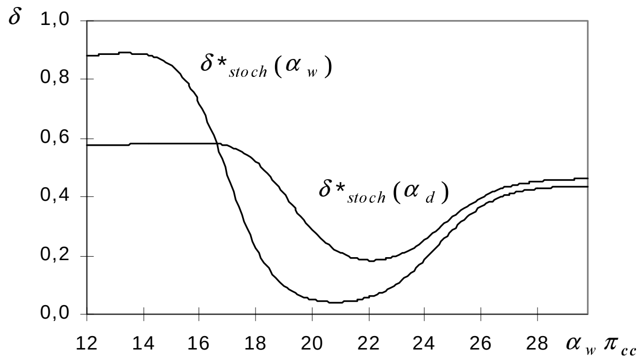

Figure 7: Stochastic variations in the amount of rainfall when $\pi_{d,c} = 1.1\pi_{c,c}$*,* $\pi_{d,d} = 0.9\pi_{c,c}$*,* $\alpha_d = 0.9\alpha_w$*, and* $p_w = 0.5$*. Note that the x-axis gives the cooperative pay-off in the wet period.*

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 rainfall levels. At $\alpha_w\pi_{c,c} \approx$MMI, a very slight change in α can cause a regime shift in terms of which period is more easy to cooperate in.

A change in the difference between the possible rainfall levels can have similarly drastic effects. According to the IPCC,[21] 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 CPR's. In Figure 8 we have increased the difference between the two possible rainfall levels 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, we have the same average amount of rainfall in the two cases. Comparing the two figures, we find quite a dramatic increase in the critical discount factor of the dry period. Unless

[21] See e.g. Houghton, Callander and Varney, 1992.

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 would also alter the critical discount factors. Thus, there may be a hidden side-effect of global warming, which has the potential to cause substantial costs to society, both in terms of conflicts and in terms of a less efficient use of local natural resources.

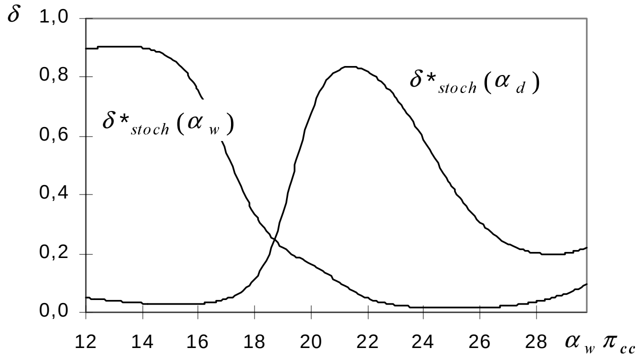

Figure 8: The effects of an increased variability in rainfall, $\pi_{d,c} = 1.1\pi_{c,c}$, $\pi_{d,d} = 0.9\pi_{c,c}$, $\alpha_d = 0.7\alpha_w$, *and* $p_w = 0.5$.

5 Partial Cooperation

Now, if the farmers know that cooperation will fail because in some periods it is not possible to sustain cooperation, is there an alternative strategy which could improve their situation? There are empirical examples of CPRs where the users forgive fellow users that break the rules if they do it due to bad times. André and Platteau (1998) in their study of land relations in Rwanda 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. We shall examine here whether the chances for cooperation can be increased by taking a more forgiving attitude.[22]

First of all, define easy periods as periods when the farmers' discount factor, δ, is at least as large as the critical discount factor, δ^*, and difficult periods as periods when it is not. Thus, cooperation is possible in easy periods only. Let the variable θ describe whether cooperation could have been credibly sustained in period t or not:

$$\theta_t = \begin{cases} 1 & if \quad \delta \geq \delta_t^*; \\ 0 & if \quad \delta < \delta_t^*. \end{cases} \tag{17}$$

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

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

$$a_t = \{a_{1,t},\ a_{2,t}\}\,. \tag{18}$$

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

$$h_T = \{a_t,\ \theta_t\}_{t=0}^{T-1}\,. \tag{19}$$

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

$$h_T = \{a_{i,t} = d,\ \theta_t = 1\} \qquad some\, t < T,\ some\, i, \tag{20}$$

and then deviate for ever. Deviations in difficult periods, $\theta_t = 0$, will be forgiven and are not punished. This means that we must adjust the expected cost of deviating to the removal of the punishment in the difficult period. Substituting from equation (12), if we let the farmers ignore deviations in dry years, the two expected utilities in the denominator of equation (14) become

$$\begin{aligned}
&E_\tau\left[U\left(\alpha_\tau\pi_{c,c}\right)\right] - E_\tau\left[U\left(\alpha_\tau\pi_{d,d}\right)\right] \\
&= p_w U\left(\alpha_w\pi_{c,c}\right) + \left(1-p_w\right)U\left(\alpha_d\pi_{d,d}\right) \\
&- p_w U\left(\alpha_w\pi_{d,d}\right) + \left(1-p_w\right)U\left(\alpha_d\pi_{d,d}\right) \\
&= p_w\left[U\left(\alpha_w\pi_{c,c}\right) - U\left(\alpha_w\pi_{d,d}\right)\right].
\end{aligned} \tag{21}$$

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

$$\delta^x_{stoch}\left(\alpha_w\right) = \frac{U\left(\alpha_w\pi_{d,c}\right) - U\left(\alpha_w\pi_{c,c}\right)}{U\left(\alpha_w\pi_{d,c}\right) - U\left(\alpha_w\pi_{c,c}\right) + p_w\left[U\left(\alpha_w\pi_{c,c}\right) - U\left(\alpha_w\pi_{d,d}\right)\right]}, \tag{22}$$

and the equivalent for the dry period being the easy period. We want to compare lower of these with

$$\delta^*_{max} = max\left\{\delta^*_{stoch}\left(\alpha_d\right), \delta^*_{stoch}\left(\alpha_d\right)\right\}. \tag{23}$$

When δ^x_{stoch} 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 for cooperation. If the farmers' 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.

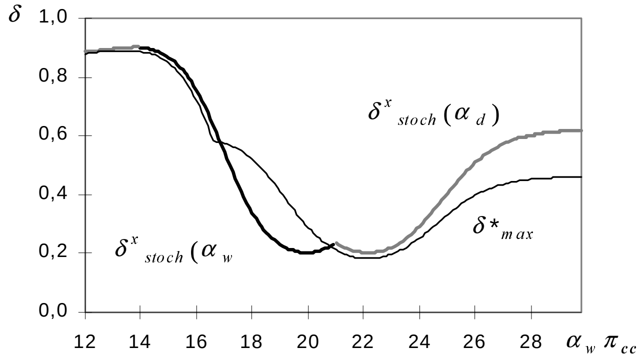

Figure 9: The effect of forgiveness with stochastic variations in the level of rainfall, $\pi_{d,c} = 1.1\pi_{c,c}$*,* $\pi_{d,d} = 0.9\pi_{c,c}$*,* $\alpha_d = 0.9\alpha_w$*, and* $p_w = 0.5$*.*

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 deviating gives a higher gain when demand is high. To avoid a total breakdown of the cooperation the oligopoly allows for a lower price in such periods, i.e. deviations are forgiven to a certain extent. Here, too, a total breakdown of cooperation can be avoided by forgiving deviations in periods when the gain from deviating is particularly high. The difference is that we measure the gain in terms of utility instead of material payoffs, and that we do not allow for partial deviations.

6 Final Remarks

In this paper I have shown that the consumption level of the users of a local CPR affects the chances of cooperative management of the resource. The results correspond well with empirical studies on what makes cooperation work or fail. In particular, we saw that groups of users with an intermediate consumption level, here meaning poor but not starving, will have the best chances for cooperative management. If the size of the resource varies, the relatively worse period will be the largest threat to cooperation for this group.

The model builds on some assumptions that may seem rather restrictive. We confine ourselves 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, we assume that they have no access to goods or credit markets. Nevertheless, when we place the local CPR's in one of the least developed countries, neither of these assumptions is at all implausible.

Throughout the paper we have assumed implicitly that there is no time dependence, 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 what the farmers do one period have an effect on the productivity of the resource in future periods, would of course 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), it would be more realistic to assume that monitoring is costly, imperfect and of varying intensity, and that there are other forms of punishment, of varying severity. Both monitoring and punishments are aspects that should be dealt with before trying to evaluate the model empirically.

It would be interesting to extend the model to more than two users, so that the more farmers that are 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 depend partly on how the irrigation system is managed, partly on annual rainfall and also partly on how many farmers that 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 we have discussed in this paper.

Appendix A: Seasonal Variations

We analyse here seasonal variations in the amount of water in the irrigation system. Many areas have a rainy season and a 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. We assume again that there are only two possible outcomes, wet and dry, but here we let every other period be wet and every other period dry. Thus, we have 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 decides the expected loss of 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 rainfall levels in the wet and dry seasons, with $\alpha_w \geq \alpha_d$. In a wet season the discounted utility of cooperating will be

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

and the discounted utility of deviating

$$U \left(\alpha_w \pi_{d,c} \right) - U \left(\alpha_w \pi_{d,d} \right) + \sum_{t=0}^{\infty} \delta^{2t} \left[U \left(\alpha_w \pi_{d,d} \right) + \delta U \left(\alpha_d \pi_{d,d} \right) \right]. \tag{25}$$

To avoid deviation, it must be true that

$$\begin{aligned} &\delta^2 \left[U \left(\alpha_w \pi_{d,c} \right) - U \left(\alpha_w \pi_{d,d} \right) \right] \\ &+\delta \left[U \left(\alpha_d \pi_{c,c} \right) - \delta U \left(\alpha_d \pi_{d,d} \right) \right] \\ &+U \left(\alpha_w \pi_{c,c} \right) - U \left(\alpha_w \pi_{d,c} \right) \\ &\geq 0. \end{aligned} \tag{26}$$

We can express the critical discount factor of a wet season[23] as

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

[23] Note that we disregard the negative root.

and the critical discount factor of a dry season

$$\delta^*_{seas}(\alpha_d) = -\frac{U(\alpha_w \pi_{c,c}) - \delta U(\alpha_w \pi_{d,d})}{2(U(\alpha_d \pi_{d,c}) - U(\alpha_d \pi_{d,d}))} + \left\{ \left[\frac{U(\alpha_w \pi_{c,c}) - \delta U(\alpha_w \pi_{d,d})}{2(U(\alpha_d \pi_{d,c}) - U(\alpha_d \pi_{d,d}))} \right]^2 + \frac{U(\alpha_d \pi_{d,c}) - U(\alpha_d \pi_{c,c})}{U(\alpha_d \pi_{d,c}) - U(\alpha_d \pi_{d,d})} \right\}^{1/2}. \tag{28}$$

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 equal probability of the two outcomes. The slight difference there is, is caused by the difference in the expected cost of deviating.

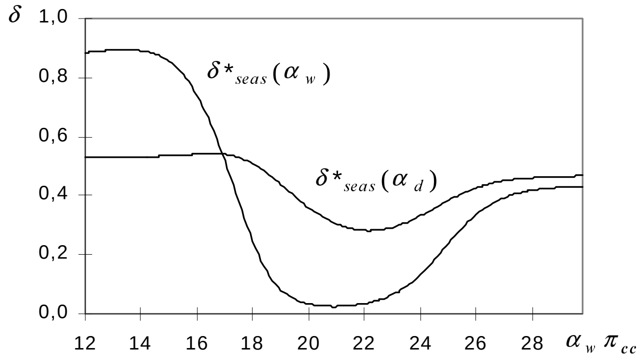

Figure 10: Seasonal variations in the level of rainfall when $\pi_{d,c} = 1.1\pi_{c,c}$, $\pi_{d,d} = 0.9\pi_{c,c}$, and $\alpha_d = 0.9\alpha_w$.

Appendix B: Partial Cooperation with Seasonal Variations

In this appendix we confirm that a forgiving attitude can increase the chances for cooperation in the seasonal case 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,

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

and from deviating

$$U(\alpha_w \pi_{d,c}) - U(\alpha_d \pi_{d,d}) + \sum_{t=0}^{\infty} \delta^{2t} \left[U(\alpha_w \pi_{d,d}) + \delta U(\alpha_d \pi_{d,d}) \right]. \tag{30}$$

From this we get the critical discount factor,

$$\delta^x_{seas}(\alpha_w) = \frac{U(\alpha_w \pi_{d,c}) - U(\alpha_w \pi_{c,c})}{U(\alpha_w \pi_{d,c}) - U(\alpha_w \pi_{d,d})}, \tag{31}$$

i.e. 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 the farmers are more forgiving.

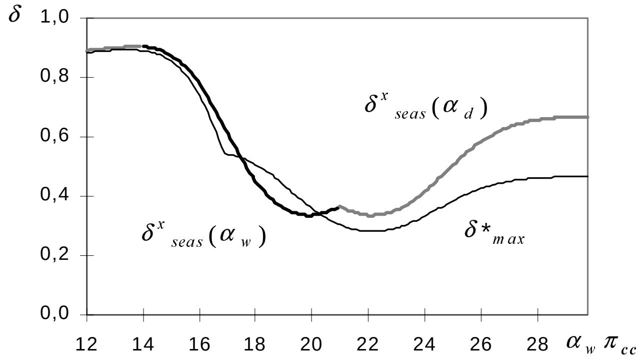

Figure 11: The effect of forgiveness with seasonal variations in the level of rainfall, when $\pi_{d,c} = 1.1\pi_{c,c}$, $\pi_{d,d} = 0.9\pi_{c,c}$, $\alpha_d = 0.9\alpha_w$.

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