Potential of Successful Voluntary Participation in Effort Regulation Programme in Common Property Resource Field Nested in Private Property Regime with Inequality

Lekha Mukhopadhyay[1]

Abstract*: This paper examines the potential of successful voluntary participation in effort regulation programme to check over utilization and thus degradation of common property resources (CPR) in a society where CPR is nested under private property regime with inequality. With a hypothetical example of agro-pastoral village community under the threat of resource degradation in the coming future, it shows that potential decline in marginal effectiveness of effort will be more for 'rich' cattle owner. This cannot however lead to the Olson conclusion that rich will have more incentive to restrain use of common resources. It is assumed that fodder collector's potential urge to increase per cattle effort in future decreases as marginal effectiveness of effort due to overuse of forest decreases. In the hypothetical example, the case of voluntary participation is considered by assuming that each individual member in the community individualistically tries to solve the problem of optimal allocation of present and future effort in CPR field. The solution is a path dependent solution: individual's choice of deploying effort at present depends on the remaining stock of CPR which is determined from community's total action or effort taken in the past for CPR extraction. In a two-stage effort allocation game in CPR field with backward induction strategies, at the outset of degradation of CPR , the paper further shows that (i) Per cattle effort for fodder collection of the 'rich' cattle owner will be greater than that of the 'poor' if the output benefit using community forest of the 'rich' in proportion to that of the 'poor' is greater than the cattle holding of the 'rich' in proportion to that of the 'poor' (ii) It will be lesser than that of the 'poor' if the output benefit using community forest of the 'rich' in proportion to that of the 'poor' is lesser than the cattle holding of the 'rich' in proportion to that of the 'poor' (iii) CPR regulation through voluntary optimal choices are determined by their respective sizes of PPR holding in relation to their total effort endowment. And finally it shows the impact on optimal choices when comlementarity restriction (i.e., increasing milk output, the benefit from CPR can not be increased further just by increasing fodder collection) and effort endowment restriction act as binding constraint. Finally, all these theoretical exercises purport to show different ranges of values of effort the regulator have to fix in different situation for ensuring voluntary participation in effort regulation programmes and its implication in policy framework for management of common property resources.*

Key words: effort endowment restriction, complementarity restriction on effort, effectiveness of effort, effort allocation game in community forest with backward induction strategies

Introduction

Collective action for conservation of common property natural resources (CPR) may take various forms: (1) development of institutions for rules and regulations for management of CPR, (2) mobilization of private resources like effort and money for protection and maintenance of CPR, (3) coordination of activities to minimize the congestion externality in CPR field and (4) information sharing, like, sharing the CPR harvesting technology and so on. The practical experiences with variant institutions for CPR management however have developed a set of theoretical puzzles; two of which in the present context to mention are concerned with: (i) relation between

[1] Department of Economics, Jogamaya Devi College, 92 S.P Mukherjee Road, Calcutta 700026 India, E Mail: lekhamukherjee@yahoo.co.in, Telephone: 011-91-33-24104535, FAX: 011-91-33-24127905

This paper has been principally developed from the Working Paper (no. 02-07) in Department of Economics University of California, Riverside, which is a part of the research supported by the Ministry of Environment and Forest, Government of India, through Overseas Post-doctoral Fellowship under World Bank India Capacity Building Programme in Environmental Economics I express my deepest gratitude to Prasanta Pattanaik for his sincere guidance, discussion and comments on that work..

heterogeneity and prospective collective action in CPR management, and (ii) relation between physical condition of CPR and prospective collective management. Sometimes community's non-acceptance of collective management institutions of CPR endogenously produces heterogeneity like income-wealth variability and so on. Sometimes heterogeneity themselves like locational differences (in case of head-end and tail-end farmers in irrigation system), income-wealth variability (like cattle ownership, ownership of fishing net, agricultural land holding etc) differential time preferences (i.e., preference between present and future consumption; Ostrom, Passim), exogenously determine the prospective collective action (Baland and Patteau, Handbook 2002). The physical condition of CPR also plays important role in framing up community's decision to cooperate or not to cooperate in collective conservation programme. The villages with acute water scarcity exhibit less cooperative management in some studied villages in Mexico and South India (Bardhan and Johnson, 2002). If due to degradation, yield of CPR is unpredictable and risky and collective management can generate some risk pooling and risk sharing benefit, then possibility of cooperation increases (Runge, 1981; Dasgupta, 1993; McKloskey, 1976). In villages in Swiss Alps, in fertile lands in the lower valley, private appropriations easily occur in contrast to arid highlands used as community pasture under the management of village councils (Netting, 1972, 1976, 1981). At the backdrop of ecological and economic complexity constituted by resource condition and heterogeneous benefit and cost of different resource users from common resources, collective action in CPR management can evolve successfully if over all for the community, there exists possibility of forming at least one minimal coalition of CPR users for whom benefit from enforcement of collective management rules is greater than over all costs ((i) up-front cost of time and effort for devising rules, (ii) short term cost for self restrained strategies, and (iii) long term cost for maintenance of rules) (Ostrom, 1999).

In a heterogeneous society with unequal distribution of private wealth or resources, CPR users may have different impact of resource degradation over time period on the effort deployed for harvesting common resources as well as on the output-benefit using CPR. Due to heterogeneity in private resources (PPR), used along with CPR in production of some private benefit, for different 'rich' and 'poor' CPR users different types of effort endowment restriction (i.e., effort to collect CPR per unit of PPR) and complementarity restriction (i.e., maximum CPR that can be used as complement to PPR) may work as binding constraints on their optimal choice of deploying effort in CPR field (Mukhopadhyay, 2002). All these have serious implications on initiating collective regulation regime in any of the form referred to, at the beginning. In order to launch regulated management regime on common property field, peoples' action in a non-regulated manner (i.e., in a non-cooperative fashion) to bring it about is required. This is the essence of voluntary collective action. Harnessing the linkage between resource quality and wealth inequality the main focus of this paper is addressed to a set of questions: (i) Who among the 'poor and 'rich' PPR owner will be interested more in launching CPR regulation? (ii) How one is to determine the potential of success of CPR regulation in an economically heterogeneous society under the threat of resource degradation? To lend concreteness to the problem the paper considers the example of a community forestland (CPR), which is the only source of fodder for milk production (a private good) in a community, heterogeneous with respect to cattle holding. The paper examines the potential of success of launching effort regulation (for collecting fodder) through peoples' voluntary response to the regulation. In the proposed analytical framework the results from the theoretical exercises show that given resource condition, difference in responses to regulation (in terms of restraining per cattle effort in collecting fodder) occurs due to the difference in net benefit. Resource condition determines the effectiveness of effort per unit of cattle deployed for collection of fodder. This paper shows, given the resource condition, how three important factors (i) unequal distribution of private property resources (PPR; cattle holding), (ii) the degree of substitutability of PPR by the effort used for appropriation of CPR (fodder), and; (iii) the degree of complementarity of PPR (cattle holding) to CPR (fodder) make difference in responses to regulation vis-à-vis difference in private benefit (in terms of milk production).

The paper has been organized as follows. Section 2 considers a general outline of the proposed model for thematic presentation. Section 3 gives a formal presentation of the model with derived propositions. Section 4 after compiling the results from section 3 reaches the conclusion.

2 A general outline of the model

More and more CPR is congested, effectiveness of deploying effort in CPR field declines. In the context of inequality in distribution of private resources (PPR) used with CPR for production of private good, effectiveness declines with the size of holding PPR. Now suppose some agent (say conservationist) external to the community, to check congestion, wants to launch effort regulation through voluntary collective action. Whether each member will like to participate in effort regulation programme or not, is to be determined by solving his problem of optimal allocation of effort between 'present' and 'future' in the CPR field, which is a path dependent solution.

Consider an agro-pastoral community in which forest is the only source of fodder for feeding cattle to produce milk output. Forest is restricted to the community members only. If regulation is introduced there will be effort regulation in terms of say, restricting weekly the number of days for each member households to go to forest for collecting fodder. More forest-pasture is degraded for congestion; herder has to go further from the village to collect fodder. This implies that he has to spend more time for fodder collection for each of the cattle owned so that, effectiveness of effort for milk output through the effort for fodder collection will decline.[2] Since regulation programme is proposed to occur through voluntary collective action, choice to follow (contend) or not to follow (defect) regulation is open to each community member.

The theme of this paper has been textured in terms of a two-player-two stage (considered here as two periods, `present' and `future') game in community forest field with backward induction strategies. 'Players' are heterogeneous with respect to cattle holding i.e., cattle property (which is private property resource for milk production) is unequally distributed. All members of the community are engaged in production of milk and for that they depend on forest, the CPR, which is the only source of fodder. The pasture has a finite stock of fodder, which grows in these two periods at a constant rate of the initial stock.

Now the production of milk of each of the member of the society depends on (i) the size of her cattle property, (ii) the effort she puts for each cattle for collection of fodder and (iii) some externality regarding how much fodder from the existing stock has been collected by other members in the society, given her own collection. Her production of milk (which is also considered as payoff in the model) is solely dependent on her own effort/ action (i.e., independent of other's effort/ action in the community) as long as total effort deployed by the society for collection of fodder doesn't exceed the total stock. In other words, how far per cattle effort deployed in collection of fodder would be effective for production of milk depends upon the congestion externality. If forest for fodder collection is not congested, herder may get production of milk, as much as effort she puts up to some optimal level of fodder, given the number of cattle she owns (cattle are assumed to be equally productive), and given the production technology.

The problem of congestion externality in the model has been transcribed with a dynamic perspective in two period's game. The set of players and distribution of cattle property are assumed to remain the same between these two periods.[2] Given the backward induction strategy, the individual player being at the `present' (stage 1) anticipates the effect of her present period collection of fodder and that of her opponent, on her future period collection and the future period stock of fodder. On the basis of this anticipation she chooses present period's sub-game perfect Nash equilibrium strategy to maximize milk production (payoff) in these two periods. Since our model deliberately assumes non-existence of past before period 1 and non-existence of any future beyond period 2, given the finite stock of fodder, assuming equal endowment of effort for each player in each period, this finite two-stage game of perfect information shows how individual players with different size of cattle holding in a non-cooperative way solve the problem of optimal allocation of per cattle effort (vis-à-vis, per cattle collection of fodder) between these two periods.

Among the infinite number of choices of action paths of the players this model however restricts to a few of them. It considers the phenomena if someone wants to introduce restriction on effort for fodder collection at 'present', what would be the Nash choice of action / per cattle effort given that there is an over all threat of breaking

[2] his proposition is similar to that made by Jodha (W B Discussion Paper; 2002).

the rules for fodder collection in future in the community.

Regarding allocation of effort in the model two possible restrictions on per cattle effort have been taken into consideration. Firstly it is assumed that total effort endowment is fixed for each player (say 24 hours a day). Maximum possible effort per cattle for collecting fodder decreases with increase in the number of cattle holding. If we assume that effort cannot be hired then for declining stock of fodder to collect fodder it may not be possible to increase per cattle effort further for the 'rich' (in terms of cattle holding) player. This binding constraint for the 'rich' player on effort allocation is termed as effort endowment restriction. The second kind of restriction on per cattle effort comes out from technological complementarity of fodder (the CPR units) to milk output.[3] If there is sufficient stock of fodder more effort for collecting fodder per cattle increases more milk production but up to a certain point, not beyond that. This complementarity restriction in turn imposes restriction on substitutability of cattle by effort. Because of this complementarity restriction, one cannot compensate the loss of milk production (i.e., the loss of payoff) due to small size of cattle property just by increasing per cattle effort for collection of fodder. This 'complementarity restriction' may be the binding constraint for the 'poor' player on his effort allocation problem. The consequences of both these binding constraints on players' decision to contend or defect effort regulation have been examined in the paper.[4]

The general conclusion we derived from our theoretical exercises is that, in a private property regime with unequal distribution of private property (the cattle property in our model) equal effort per unit of PPR (vis-à-vis., equal level of per cattle collection of fodder) doesn't necessarily lead to equal benefit (i.e., equal level of production of milk) and vice versa.

3. A Simple Common Property Resources Game in Community Forest for Fodder Collection with Backward Induction Strategies

3.1 Model Specification

Consider a society of two players, N ={1,2}, with a finite time horizon of two periods, T={1,2}, the 'present' and 'future', with no 'past'. The life span of each player is assumed to cover these two periods. There is a common property resource, say, forest, with a finite stock of fodder, which is, at the beginning of the game is S and grows by Δ between these two periods. $\Delta < S$, is a simple follow-up of the existing trend in the literature handling with the dynamics of the natural growth of renewable resources: growth of resources is a decreasing function of the size of resource stock. Jorgensen and Yeung (1999)). The players collect fodder from the forest to feed the cattle since open grazing in this society is not allowed. The cattle are homogeneous in terms of productivity. There is inequality in the distribution of cattle properties (K), so that the number of cattle owned by the *ith* player, is assumed to be less than the number of cattle owned by the *jth* player (assuming, *i*=1and *j*=2). For each of the *ith* player K_i is assumed to be the same across the periods and so is K_j.

The interaction of the players determines the amount of fodder that each player will collect from the forest in each period. The final outcome however is interdependent of players' decisions. Since this is a two period game, the move in the second period (`future') is conditioned by the outcome of the first, (`present') i.e. by the history of the game till the second stage is reached. This implies that each of the player's strategy is a complete plan of action for the whole game.

[3] Dasgupta, 2000; Dasgupta, 1987; Jodha,1986;1990, have described how poor rural folk with the help of some degree of substitutability of capital by common pool/ property resources manage to survive. CPR in that context play some remissive role on inequality

[4] In order to lend concreteness to the problem fodder collection game in community forest has been metaphorically used. The results will not significantly change if it could be otherwise the problem of effort allocation with different sizes of fishing nets (or boats) or agricultural land holding in case of coastline fishing or ground water collection for irrigation, and so on.

Let $a_i^{\,t}$ effort per unit of cattle (expressed in terms of labour hours), deployed for collection of fodder, be the action variable of the *ith* player in period t. Given the number of cattle K_i fixed, and given the fixed endowment of total effort, E_i for each player in each period: $a_i^{\,t} \in \{0, \frac{E_i}{K_i}\} \to \Re_+$. It is assumed that, $E_i = E_j$, so that total effort endowment of each of the player in each period is the same although the per cattle effort endowment of *ith* player is less than that of *jth* player, i.e., $\frac{E_i}{K_i} < \frac{E_j}{K_j}$. At the beginning of the period, 1 say, `present' since the stock of fodder is $S^1 = S$ , and between these two periods, the stock grows by $\Delta$, in period 2, say `future' the maximum available fodder (if nothing is used in the `present') is, ($S + \Delta$).

3.1.1 Specification of production (or payoff) function

The production function (also the payoff function) of milk in this model has two-parts; first part considers the total effort used for collection of fodder ($= K_i a_i^{\,t}$) and the second part constitutes the `effectiveness' of effort ($\psi_i^{\,t}$) which depends on congestional externality effect. If there is no congestion externality, i.e., there is enough stock let $\psi_i^{\,t} = 1$ and less than 1 if congestion matters:

D 1. The production function (also the payoff function) of milk of the *ith* player at period *t*, $Q_i^{\,t}$ is defined as a function of total effort, $(= K_i a_i^t)$, and the 'effectiveness' function ψ_i^t, such that,

$$Q_i^{\,t} = K_i a_i^t \, \psi_i^t$$

where, $\psi_i^t = \dfrac{S^t}{\sum K_i a_i^t}$

The effectiveness is a function of proportion of CP stock to community effort. If $\dfrac{S^t}{\sum K_i a_i^t} \geq 1$, i.e stock is not over-exploited $\psi_i^t = 1$. If otherwise, $0 \leq \dfrac{S^{\langle t \rangle}}{\sum K_i a_i^{\langle t \rangle}}) < 1$; $0 \leq \psi_i^{\langle t \rangle} < 1$.[5] As $\sum K_i a_i^{\langle t \rangle}$ increases beyond $S^{\langle t \rangle}$ the effectiveness of effort $\Psi_i^{\langle t \rangle}$ declines, taking the values less than one. The effectiveness curve is graphically shown in Figure 1.

---

[5] Mukhopadhyay (2002) has expressed ψ_i^t explicitly ψ_i^t as an exponential function which is as follows:. $\psi_i^{\,t} = e^{x^t - 1}$ where, $x^t - 1 = \dfrac{S^t}{K_i a_i^{\,t} + K_j a_j^{\,t}} - 1 = \dfrac{S^t - (K_i a_i^{\,t} + K_j a_j^{\,t})}{K_i a_i^{\,t} + K_j a_j^{\,t}}$, where x^t is the proportion of forest stock over the total effort of the community for collection of fodder in period *t*.

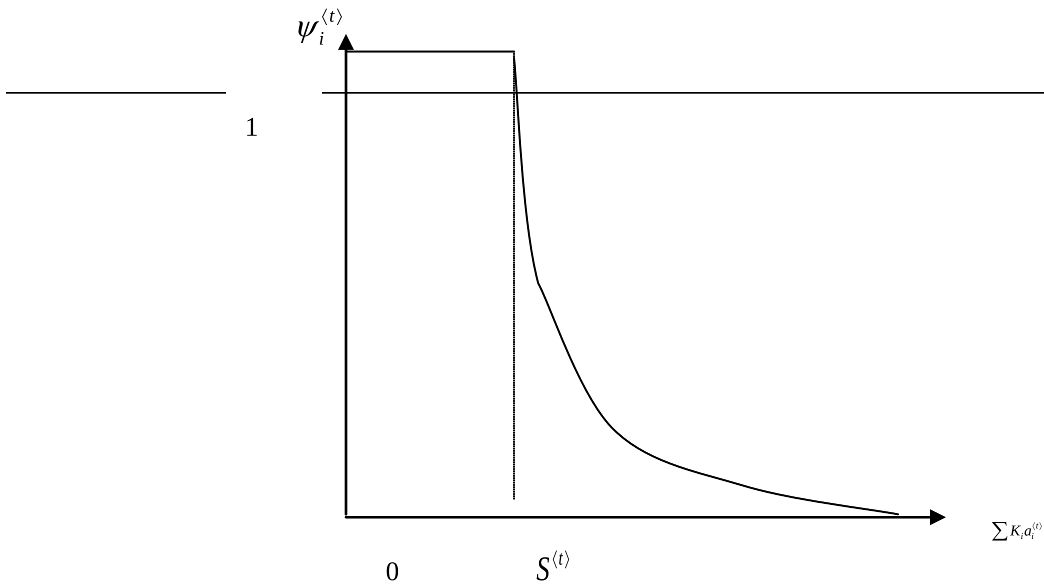

Figure 1

More and more CPR is congested, effectiveness of deploying effort in CPR field declines. Here the objective of each individual member in the community is optimal allocation of effort at present and at future in the CPR field, which is a path dependent solution. The effectiveness of deploying effort in CPR field has an inflictive role on players' optimal allocation problem.

3.1.2 Compementarity restriction on milk production or payoff function

In the production or payoff function per cattle effort for fodder collection, a_i^t is complementary to the milk production. Other things remaining the same, as per cattle fodder collection increases, as a complementary effect milk production also increases. But there is a limit to this complementarity. There is so far no restriction imposed on complementarity. Given the number of cattle K_i, if the effectiveness factor ψ_i^t =1, i.e., forest is not congested, milk production increases with a_i^t up to say, $\underline{a}$. Beyond $\underline{a}$ with ψ_i^t being equal to 1, milk production per cattle remains unchanged. If effectiveness $\psi_i^t < 1$, i.e., forest is congested more effort will be required for each cattle to collect fodder. In that case, complementarity restriction will be different; say, $\overline{a}$. Obviously, $\underline{a} < \overline{a}$.

Incorporating complementarity restriction into the production (also the payoff) function, in this way, we are now able to handle with two distinct possibilities; one, where, complementarity restriction acts as a binding constraint and the other, where the complementarity restriction does not bind the individual's choice of per cattle action in the common property field. If for the i th player, complementarity restriction acts as the binding constraint, there are two possibilities:

(C1) $Q_i^t = K_i \underline{a}$, if forest is not congested;

(C2) $Q_i^t < K_i \overline{a}$, if forest is congested; $\overline{a} > \underline{a}$.

Possibility (2) indicates that if forest is congested, and ith player has already reached the limit of complementary effect $\bar{a}$, because of congestion externality he would get milk output less than $K_i \bar{a}$. If for example, $\psi_i^t = \frac{1}{2}$, then $Q_i^t = K_i \frac{\bar{a}}{2}$ and this less than he could otherwise get through maximum complementary effect if forest was not congested, i.e., $K_i \frac{\bar{a}}{2} < K_i \underline{a}$. Complementarity restriction in other words, makes the production / payoff function discontinuous for $a_i^t > \underline{a}$ (or, $a_i^t > \bar{a}$) and other things remaining the same, the marginal productivity of $a_i^t > \underline{a}$ (or $a_i^t > \bar{a}$) becomes zero.[6]

D 1.1 Two- period milk production or payoff function

Since community member-players in the model are solving their problem of optimal allocation of effort between two periods: 'present' and 'future', they are concerned with two period milk production or payoff function

$$Q_i = Q_i^{\langle 1\rangle}(a_i^{\langle 1\rangle}, a_j^{\langle 1\rangle}) + Q_i^{\langle 2\rangle}(a_i^{\langle 2\rangle}(a_i^{\langle 1\rangle}, \hat{a}_j^{\langle 1\rangle}), a_j^{\langle 2\rangle}(a_i^{\langle 1\rangle}, a_j^{\langle 1\rangle})) = K_i a_i^{\langle 1\rangle}\psi_i^{\langle 1\rangle} + K_i a_i^{\langle 2\rangle}\psi_i^{\langle 2\rangle}$$

$$\cancel{- K_i a_i^{\langle 1\rangle} \frac{S^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}}) + K_i a_i^{\langle 2\rangle} \frac{S^{\langle 2\rangle}}{\sum K_i a_i^{\langle 2\rangle}}}$$

where, $S^{\langle 2\rangle} = (S^{\langle 1\rangle} - \sum K_i a_i^{\langle 1\rangle}) + \Delta$

The first part of the two period milk production or payoff is function of the set of actions of players in period 1 $(a_i^{\langle 1\rangle}, a_j^{\langle 1\rangle})$, while the second part is the function of actions of period 2, $(a_i^{\langle 2\rangle}(a_i^{\langle 1\rangle}, \hat{a}_j^{\langle 1\rangle}), a_j^{\langle 2\rangle}(a_i^{\langle 1\rangle}, a_j^{\langle 1\rangle})$. The choice of action in period 2 is contingent upon actions chosen in period 1.

3.2 Decentralized Nash solution in community forest game

The Nash solution in the two-stage community forest game with backward induction strategies gets solved by:

$$\underset{a_i^1}{Max}[Q_i^{\langle 1\rangle}(a_i^{\langle 1\rangle}, a_j^{\langle 1\rangle}) + Q_i^{\langle 2\rangle}(a_i^{\langle 2\rangle}(a_i^{\langle 1\rangle}, \hat{a}_j^{\langle 1\rangle}), a_j^{\langle 2\rangle}(a_i^{\langle 1\rangle}, a_j^{\langle 1\rangle}))]$$

i.e., by $\underset{a_i^1}{Max}[\; K_i a_i^{\langle 1\rangle} \frac{S^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}}) + K_i a_i^{\langle 2\rangle} \frac{S^{\langle 2\rangle}}{\sum K_i a_i^{\langle 2\rangle}}]$ ………(1)

The equation (1) is used as generic equation in the model. In period 2 sub-game perfect equilibrium $[a_i^{\langle 2\rangle}(\hat{a}_i^{\langle 1\rangle}, \hat{a}_j^{\langle 1\rangle}), a_j^{\langle 2\rangle}(\hat{a}_i^{\langle 1\rangle}, \hat{a}_j^{\langle 1\rangle})]$ is obtained by solving each of the following equations:

$$\frac{\partial}{\partial a_i^{\langle 2\rangle}}[k_i a_i^{\langle 2\rangle}\psi_i^{\langle 2\rangle}(.)] = 0 \quad \text{……….(2)}$$

[6] This type of complementarity restriction may provide with an alternative explanation to why in a small society over extraction of natural resources doesn't take place. One of the possible reason is that size of the capital (which comes from private resources) in that society is so small that over extraction is not economically profitable.

$$\frac{\partial}{\partial a_j^{\langle 2\rangle}}[k_j a_j^{\langle 2\rangle}\psi_j^{\langle 2\rangle}(.)] = 0 \text{ ....(3)}$$

Solving (5), we get:

$$\psi_i^{\langle 2\rangle}(.) + a_i^{\langle 2\rangle}\,\frac{\partial \psi_i^{\langle 2\rangle}(.)}{\partial a_i^{\langle 2\rangle}} = 0 \text{ ....(3.1)}$$

$\frac{\partial \psi_i^{\langle 2\rangle}}{\partial a_i^{\langle 2\rangle}}$ in the second part of L.H.S of (6.!) shows the marginal effectiveness of effort in period 2, if forest is congested, given the action of period 1 (i.e., 'present'). Since, $\frac{\partial \psi_i^{\langle 2\rangle}}{\partial a_i^{\langle 2\rangle}} = -\frac{\psi_i^{\langle 2\rangle}}{\sum K_i a_i^{\langle 2\rangle}} K_i$, and $\frac{\partial}{\partial \psi_i^{\langle 2\rangle}}\left(\frac{\partial\ \psi_i^{\langle 2\rangle}}{\partial a_i^{\langle 2\rangle}}\right) = -\frac{K_i}{\sum K_i a_i^{\langle 2\rangle}}$ we can develop Proposition 1.

Proposition 1 Given the action of period 1 (i.e., 'present'), more and more forest is congested effectiveness of effort in period 2 (i.e., 'future'), for collection of fodder (i.e., marginal effectiveness) declines in general and it declines more for 'rich' (in terms of cattle property) compared to 'poor'.

Corollary 1.1 Lesser the marginal effectiveness of effort in period 2 for the rich ($= -\frac{K_i}{\sum K_i a_i^{\langle 2\rangle}}$), lesser will be the per cattle effort for fodder collection

This is because from (3.1) we get $a_i^{\langle 2\rangle} = \frac{\psi_i^{\langle 2\rangle}(\sum K_i a_i^{\langle 2\rangle})^2}{S^{\langle 2\rangle} K_i}$, which decreases with the size of K_i

(Proof in Appendix A)

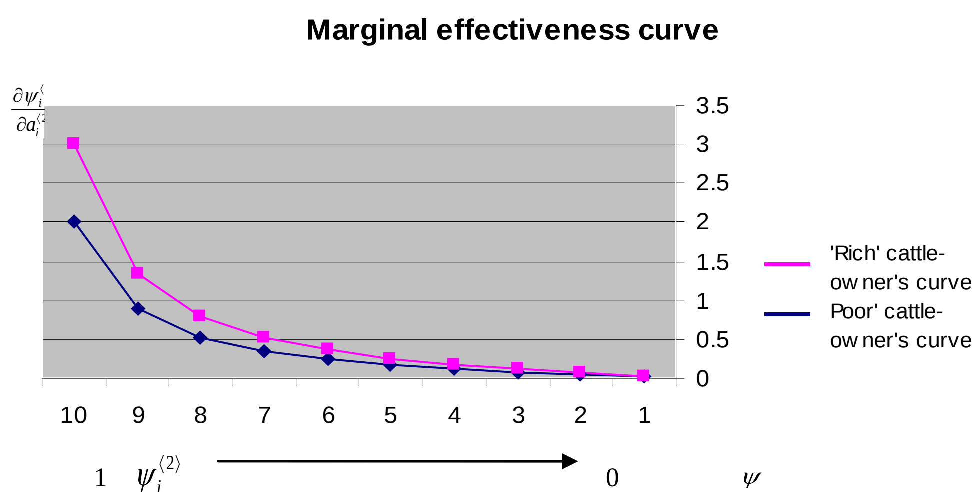

Figure 2

With an hypothetical example of the values of effectiveness of effort ranging between 0 and 1 in a community with two players heterogeneous in terms of cattle property (shown in Table 1) the marginal effectiveness curves for 'rich' and 'poor' have been plotted graphically in Figure 2.

From Proposition 1, one cannot however lead to the Olson conclusion that 'rich' will have more incentive to restrain use of common resources for future. Because it depends on 1.

Table 1

$\psi_i^{\langle 2\rangle}$	$\sum K_i a_i^{\langle 2\rangle}$	K	K_i	$\frac{\psi_i^{\langle 2\rangle}}{\sum K_i a_i^{\langle 2\rangle}} K_i$ K	$\frac{\psi_j^{\langle 2\rangle}}{\sum K_i a_i^{\langle 2\rangle}} K_j$ F
0.1	100	20	30	0.020	0.030
0.2	90	20	30	0.040	0.0666
0.3	80	20	30	0.075	0.113
0.4	70	20	30	0.0114	0.171
0.5	60	20	30	0.166	0.250
0.6	50	20	30	0.240 ψ	0.360
0.7	40	20	30	0.350	0.525
0.8	30	20	30	0.5333	0.800
0.9	20	20	30	0.9	1.350
1.0	10	20	30	2	3

3.2.1 Potentiality of voluntary acceptance of effot regulation in community forest at 'present' when there is threat of breaking regulation in 'future'

The practical experiences with voluntary collective management of community forest and other types of common property resources show a large number of instances where the collective regulation has been broken in phase 2 after successful launching of the regulation programme in phase 1 (Banerjee, 2004,). Sometimes although some authors claim (Somnathan,) in reality there is no assurance that success with collective regulation will perpetualy sustain in the long run. Thus it is plausible to assume that while introducing voluntary collective regulation of effort for fodder collection from community forest the community itself and each of the constituent member faces threat of breaking rules and regulation in future. In our proposed theoretical framework this implies that we are considering only the action path in the two-stage community forest game with backward induction strategies, which is characterized by congestion in the period 2 (i.e., 'future') i.e., $\psi_i^{\langle 2\rangle} < 1$, $\frac{\partial \psi_i^{\langle 2\rangle}}{\partial a_i^{\langle 2\rangle}} < 0$ and also $\frac{\partial}{\partial \psi_i^{\langle 2\rangle}}\left(\frac{\partial \psi_i^{\langle 2\rangle}}{\partial a_i^{\langle 2\rangle}}\right) < 0$; but $\psi_i^{\langle 1\rangle} = 1$which means forest is not congested in period 1 (i.e., 'present') due to regulation.

Since the strategy of the game is backward induction, sub-game perfect equilibrium solution in stage 2 will be rolled back into the stage 1 game. In stage 2 there are two possible cases: Case (1): Neither by complementarity restriction nor by effort endowment restriction, per cattle effort for fodder collection is bounded; and, Case (2): Per cattle effort for fodder collection is bounded by either of these restrictions for some player.

Case 1: Per cattle effort for fodder collection is not bounded by any restriction

Solving (6.1) for *i*th and similarly for *j*th players we get following two reaction equations:

$$\psi_i^{\langle 2\rangle} - \frac{K_i a_i^{\langle 2\rangle}}{(\sum K_i a_i^{\langle 2\rangle})^2} S^{\langle 2\rangle} = 0$$

$$\psi_j^{\langle 2\rangle} - \frac{K_j a_j^{\langle 2\rangle}}{(\sum K_i a_i^{\langle 2\rangle})^2} S^{\langle 2\rangle} = 0$$

$\psi_i^{\langle 2\rangle} = \psi_j^{\langle 2\rangle}$; $\frac{K_i}{(\sum K_i a_i^{\langle 2\rangle})^2} S^{\langle 2\rangle}$ in the second part of the reaction equation shows the slope of reaction curves. Since $\frac{S^{\langle 2\rangle}}{(\sum K_i a_i^{\langle 2\rangle})^2}$ is the common part in both the equations, slope of reaction curves vary according to the size of the cattle property K_i (K_j).

As a sub-game perfect solution in stage 2, we get:

$$K_i a_i^{\langle 2\rangle} = K_j a_j^{\langle 2\rangle} \text{.....(4)}$$

which means; $a_i^{\langle 2\rangle} = \frac{K_j}{K_i} a_j^{\langle 2\rangle}$; By the model specification $\frac{K_j}{K_i} < 1$. To distinguish between two players in terms of cattle property let us denote 'rich' *i*th player now and subsequently later by the suffix r and 'poor by p and thus $a_r^{\langle 2\rangle} < a_p^{\langle 2\rangle}$.

Plugging the value from (7) i.e $\sum K_i a_i^{\langle 2\rangle} = 2K_i a_i^{\langle 2\rangle}$, into the generic equation (1), we get the decentralized Nash solution in per cattle effort:

$$\tilde{a}_r^{\langle 1\rangle} = \frac{1 - \frac{1}{2}\psi_r^{\langle 2\rangle}(1 + \psi_r^{\langle 2\rangle}\frac{\partial a_r^{\langle 2\rangle}}{\partial a_r^{\langle 1\rangle}})}{K_r} S^{\langle 1\rangle} \text{..........(5.1)}$$

$$\tilde{a}_p^{\langle 1\rangle} = \frac{1 - \frac{1}{2}\psi_p^{\langle 2\rangle}(1 + \psi_p^{\langle 2\rangle}\frac{\partial a_p^{\langle 2\rangle}}{\partial a_p^{\langle 1\rangle}})}{K_p} S^{\langle 1\rangle} \text{..........(5.2)}$$

$\tilde{a}_r^{\langle 1\rangle}$ and $\tilde{a}_p^{\langle 1\rangle}$ must satisfy the effort endowment restriction; i.e., $\tilde{a}_r^{\langle 1\rangle} \le \frac{E}{K_r}$ and $\tilde{a}_p^{\langle 1\rangle} \le \frac{E}{K_p}$. From (8.1) and (8.2), the results in Nash Solution, we can set a number of propositions:

Proposition 2 *The Nash optimal level of per cattle effort for fodder collection from community forest in 'present' under the threat of forest degradation in 'future' will*

(i) increase with present stock of fodder;

(ii) decrease with greater anticipated rate of forest degradation (i.e., decrease in effectiveness of effort) in future

$\frac{\partial a_r^{\langle 2\rangle}}{\partial a_r^{\langle 1\rangle}}$ (and $\frac{\partial a_p^{\langle 2\rangle}}{\partial a_p^{\langle 1\rangle}}$) in the Nash solution 5.1 (and 5.2) indicates the respective player's choice to change per cattle effort in period 2 ('future') in response to change in effort in period 1 ('present'). Degradation of forest due to congestion and therefore decline in effectiveness of effort is already presumed, so that, sign of $\frac{\partial a_r^{\langle 2\rangle}}{\partial a_r^{\langle 1\rangle}}$ (and $\frac{\partial a_p^{\langle 2\rangle}}{\partial a_p^{\langle 1\rangle}}$) must be positive if no complementarity restriction works as binding restriction on per cattle effort for fodder collection in period 1. It is shown in corollary 1 above that due to congestion in period 2, marginal effectiveness of effort is lesser for 'rich' player compared to 'poor' player and $a_r^{\langle 2\rangle} < a_p^{\langle 2\rangle}$. If for 'rich' per cattle effort in period 2 is lesser than that of the 'poor', we can make the following assumption:

Assumption: $0 \le \frac{\partial a_r^{\langle 2\rangle}}{\partial a_r^{\langle 1\rangle}} < \frac{\partial a_p^{\langle 2\rangle}}{\partial a_p^{\langle 1\rangle}}$, *i.e., while increasing per cattle effort due to congestion externality in period 2, 'rich' player will increase less compared that of 'poor'.*

Comparing between (5.1) and (5.2), we see that the ratio of two numerators $\frac{1-\frac{1}{2}\psi_r^{\langle 2\rangle}(1+\psi_r^{\langle 2\rangle}\frac{\partial a_r^{\langle 2\rangle}}{\partial a_r^{\langle 1\rangle}})}{1-\frac{1}{2}\psi_p^{\langle 2\rangle}(1+\psi_p^{\langle 2\rangle}\frac{\partial a_p^{\langle 2\rangle}}{\partial a_p^{\langle 1\rangle}})} > 1$ which implies $K_r\tilde{a}_r^{\langle 1\rangle} > K_p\tilde{a}_p^{\langle 1\rangle}$; i.e., total effort for fodder collection and thus total benefit from community forest of the 'rich' player will be greater than that of the 'poor'.

Now from the whole game plan in the optimal choice per cattle effort of 'rich' player will be greater than that of 'poor' i.e., $\tilde{a}_r^{\langle 1\rangle} > \tilde{a}_p^{\langle 1\rangle}$ if:

$$\frac{1-\frac{1}{2}\psi_r^{\langle 2\rangle}(1+\psi_r^{\langle 2\rangle}\frac{\partial a_r^{\langle 2\rangle}}{\partial a_r^{\langle 1\rangle}})}{1-\frac{1}{2}\psi_p^{\langle 2\rangle}(1+\psi_p^{\langle 2\rangle}\frac{\partial a_p^{\langle 2\rangle}}{\partial a_p^{\langle 1\rangle}})} > \frac{K_r}{K_p} \quad \text{......(6.1.1)}$$

Choice of per cattle effort of 'rich' player on the other hand, will be lesser than that of 'poor' i.e., $\tilde{a}_r^{\langle 1\rangle} < \tilde{a}_p^{\langle 1\rangle}$ if:

$$1 < \frac{1-\frac{1}{2}\psi_r^{\langle 2\rangle}(1+\psi_r^{\langle 2\rangle}\frac{\partial a_r^{\langle 2\rangle}}{\partial a_r^{\langle 1\rangle}})}{1-\frac{1}{2}\psi_p^{\langle 2\rangle}(1+\psi_p^{\langle 2\rangle}\frac{\partial a_p^{\langle 2\rangle}}{\partial a_p^{\langle 1\rangle}})} < \frac{K_r}{K_p} \quad \text{.......(6.1.2)}$$

Now effort regulation through voluntary participation will be potentially successful if regulator fixes effort at a^*, such that:

$$a^* \ge \tilde{a}_r^{\langle 1\rangle} > \tilde{a}_p^{\langle 1\rangle}, \text{ in case (6.1.1) occurs, or}$$

$$a^* \ge \tilde{a}_p^{\langle 1\rangle} > \tilde{a}_r^{\langle 1\rangle}, \text{ if (6.1.2) occurs}$$

Irrespective of greater ness of per cattle effort optimally chosen by 'rich' or 'poor', proportion of effort to the total community effort and therefore the milk output (benefit) of the 'rich' player will be greater than that of 'poor' player; i.e., $\frac{K_r \ \tilde{a}_r^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}} > \frac{K_p \ \tilde{a}_p^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}}$.

From the derived results now we can develop the following proposition:

Proposition 3 *If CPR (here, community forest) is nested in private property regime with inequality in distribution of PPR (here cattle property)*:

(i) Per cattle effort for fodder collection of the 'rich' cattle owner will be greater than that of the 'poor' if the output benefit using community forest of the 'rich' in proportion to that of the 'poor' is greater than the cattle holding of the 'rich' in proportion to that of the 'poor'

(ii) Per cattle effort for fodder collection of the 'poor' cattle owner will be greater than that of the 'rich' if the output benefit using community forest of the 'rich' in proportion to that of the 'poor' is lesser than the cattle holding of the 'rich' in proportion to that of the 'poor'

(iii) CPR regulation through voluntary participation will be successful if regulation sustains inequality in benefit from CPR.

(Proof is given in Appendix)

The proposition 3(i) and 3(ii) however cannot rule out effort endowment restriction, i.e., $\tilde{a}_r^{\langle 1\rangle} \le \frac{E}{K_r}$ and $\tilde{a}_p^{\langle 1\rangle} \le \frac{E}{K_p}$ and, also $\frac{E}{K_r} < \frac{E}{K_p}$. If in any case effort endowment restriction becomes the binding constraint for 'rich' player, i.e., $\tilde{a}_r^{\langle 1\rangle} = \frac{E}{K_r}$ then case (3.1): will not arise; i.e., in spite of greater potential output benefit from the forest the 'rich' player will not be able to deploy greater per cattle effort. In this case his potential loss would be. This is made under the assumption that labour hiring is not possible. If in that case he can hire labour and the cost of hiring labour is less than or equal to $(K_r \tilde{a}_r^{\langle 1\rangle} - E)$, then he can still invest greater effort for fodder collection to reap greater benefit

Case 2: Per cattle effort for fodder collection is bounded by complementarity restriction

Complementarity restriction in period 1: Let in period 1 complementarity restriction $(\bar{a})$ works as binding constraint. $\bar{a} \in \Re_+$, i.e., $\bar{a}$ is any real number which is exogeneously given. Now we may consider the following four logical possibilities in each of the cases (6.1.1) and (6.1.2) with different ranges of values that $\bar{a}$ can take in relation to the first stage sub-game values:

Case (6.1.1): $\tilde{a}_r^{\langle 1\rangle} > \tilde{a}_p^{\langle 1\rangle}$	Case (6.1.2): $\tilde{a}_r^{\langle 1\rangle} < \tilde{a}_p^{\langle 1\rangle}$

Possibility 1.1: $\tilde{a}_r^{\langle 1\rangle} > \tilde{a}_p^{\langle 1\rangle} \geq \bar{a}$	*Possibility* $\tilde{a}_p^{\langle 1\rangle} > \tilde{a}_r^{\langle 1\rangle} \geq \bar{a}$
Possibility 1.2: $\tilde{a}_r^{\langle 1\rangle} \geq \bar{a} > \tilde{a}_p^{\langle 1\rangle}$	*Possibility 2.2:* $\tilde{a}_p^{\langle 1\rangle} \geq \bar{a} > \tilde{a}_r^{\langle 1\rangle}$
Possibility 1.3: $\bar{a} \geq \tilde{a}_r^{\langle 1\rangle} > \tilde{a}_p^{\langle 1\rangle}$	*Possibility 2.3* $\bar{a} \geq \tilde{a}_p^{\langle 1\rangle} > \tilde{a}_r^{\langle 1\rangle}$

Now to make effort regulation through voluntary participation successful if regulator fixes effort at a^*, such that: $a^* \geq \tilde{a}_r^{\langle 1\rangle} > \tilde{a}_p^{\langle 1\rangle}$, in case (6.1.1), in possibility 1.1 this implies $a^* \geq \tilde{a}_r^{\langle 1\rangle} > \tilde{a}_p^{\langle 1\rangle} \geq \bar{a}$. In possibility 1.2, it leads to $a^* \geq \tilde{a}_r^{\langle 1\rangle} \geq \bar{a} > \tilde{a}_p^{\langle 1\rangle}$ and in possibility1.3, it is little bit tricky because it is possible that either, $a^* \geq, or \leq \bar{a}$.

In possibility (1.1) since complementarity restriction becomes the binding constraint for both the players, the potentiality for successful voluntary participation is maximum.

In possibility (1.2) since complementarity restriction becomes the binding constraint for ‘rich’ player, the potentiality for successful voluntary participation still exists.

In possibility (1.3), if in particular, $a^* < \bar{a}$ evolving successful voluntary participation in effort regulation becomes extremely difficult.

Similar types of inferences can be made in case (6.1.2) occurs.

4. Conclusion

With the help of a simple model of agro-pastoral village society producing milk with cattle (private property, which is unequally distributed) and fodder (which is collected from forest, a common property) this paper examines the potential of successful voluntary participation in effort regulation programme. For the purpose of conservation of common property resources most of the community based organization in various forms like periodical closure of CPR field (like that in pasture land), restricting the number of head loads, or the number of days for fodder collection, restricting size of fishing net or number of boats etc make attempt to introduce effort regulation programme as a part of management of common property resources. If in a community there is inequality in private property resources which is used along with CPR to produce some private benefit it affects individual's optimal choice for allocation of effort in the common property field and individual's as well as society's benefit from the common property resources. In that case reaction to the effort regulation programme and the choices to contend or defect the rules vary from individual to individual due to inequality. It is due to inequality reaction to resource degradation also varies between individuals. In a generalized version of a two-player, two-stage game for effort allocation for collecting fodder from the forest with backward induction strategies the inequality issue has been handled here in two different contexts. Firstly it has considered a situation where inequality itself is manifested through unequal per cattle effort endowment, where per cattle effort endowment for the `rich' cattle owner is less compared to the `poor' owner. Secondly, it has considered a situation where in conjunction with per cattle effort endowment there exists a limit on per cattle action (or effort) beyond which milk production cannot be increased, which is called complementarity restriction in the model. In these context sub-game perfect Nash solution to the problem of individual's allocation of effort has been derived and characterized in terms of the four parameters in the model, viz., cattle property, effort endowment, stock condition of fodder in the forest in comparison with the total community effort for harvesting from the stock, and complementarity restriction.

4.1 Summary of Results

The results from the exercises under the proposed analytical frame work have been expresses in terms of a set of propositions that can be summarized as follows:

Given the action of period ‘present’ more and more forest is congested effectiveness of effort in ‘future’, for collection of fodder (i.e., marginal effectiveness) declines in general and it declines more for ‘rich’ (in terms of cattle property) compared to ‘poor’. Lesser the marginal effectiveness of effort in ‘future’ for the rich, lesser will be the per cattle effort for fodder collection

The Nash optimal level of per cattle effort for fodder collection from community forest in ‘present’ under the threat of forest degradation in ‘future’ will (i) increase with present stock of fodder; (ii) decrease with greater anticipated rate of forest degradation (i.e., decrease in effectiveness of effort) in future

If CPR (here, community forest) is nested in private property regime with inequality in distribution of PPR (here cattle property):(i) Per cattle effort for fodder collection of the ‘rich’ cattle owner will be greater than that of the ‘poor’ if the output benefit using community forest of the ‘rich’ in proportion to that of the ‘poor’ is greater than the cattle holding of the ‘rich’ in proportion to that of the ‘poor’ (ii) Per cattle effort for fodder collection of the ‘poor’ cattle owner will be greater than that of the ‘rich’ if the output benefit using community forest of the ‘rich’ in proportion to that of the ‘poor’ is lesser than the cattle holding of the ‘rich’ in proportion to that of the ‘poor’ (iii) CPR regulation through voluntary participation will be successful if regulation sustains inequality in benefit from CPR.

Finally, the results in the proposed analytical framework have the far-reaching implications on policy matters. Under different conditions it shows different upper bands of effort (conformable to Nash equilbria) restriction that regulator can fix up in a community with CPR, for conservation of CPR. Since these bands are obtained from Nash equilibria and take into account complementarity and effort endowment restrictions (whenever they are binding constraints) they are also imlementable through voluntary participation.

Appendix 1

The Nash solution in the two-stage CPR game with backward induction strategies gets solved by :

$$\underset{a_i^1}{Max}[Q_i^{\langle 1\rangle}(a_i^{\langle 1\rangle}, a_j^{\langle 1\rangle}) + Q_i^{\langle 2\rangle}(a_i^{\langle 2\rangle}(a_i^{\langle 1\rangle}, \hat{a}_j^{\langle 1\rangle}), a_j^{\langle 2\rangle}(a_i^{\langle 1\rangle}, a_j^{\langle 1\rangle}))] \text{ i.e., by}$$

$$\underset{a_i^1}{Max}[\, K_i a_i^{\langle 1\rangle}\psi_i^{\langle 1\rangle}(\frac{S^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}}) + K_i a_i^{\langle 2\rangle}\psi_i^{\langle 2\rangle}(\frac{S^{\langle 2\rangle}}{\sum K_i a_i^{\langle 2\rangle}})\,] \text{ ....(1)}$$

The choice of action in period 2 is contingent upon actions chosen in period1. In period 2 sub-game perfect equilibrium $[a_i^{\langle 2\rangle}(\hat{a}_i^{\langle 1\rangle}, \hat{a}_j^{\langle 1\rangle}), a_j^{\langle 2\rangle}(\hat{a}_i^{\langle 1\rangle}, \hat{a}_j^{\langle 1\rangle})]$ is obtained by solving each of the following equations:

$$\frac{\partial}{\partial a_i^{\langle 2\rangle}}[k_i a_i^{\langle 2\rangle}\psi_i^{\langle 2\rangle}(.)] = 0 \text{ ....(5)}$$

$$\frac{\partial}{\partial a_j^{\langle 2\rangle}}[k_j a_j^{\langle 2\rangle}\psi_j^{\langle 2\rangle}(.)] = 0 \text{ ....(6)}$$

Solving (5), we get:

$$\psi_i^{\langle 2\rangle}(.) + a_i^{\langle 2\rangle}\frac{\partial\psi_i^{\langle 2\rangle}(.)}{\partial a_i^{\langle 2\rangle}} = 0$$

Here in particular, $\psi_i^{\langle 2\rangle} = \frac{S^{\langle 2\rangle}}{\sum K_i a_i^{\langle 2\rangle}} = \frac{S^{\langle 1\rangle} - \sum K_i a_i^{\langle 1\rangle} + \Delta}{\sum K_i a_i^{\langle 2\rangle}}$

$$\frac{\partial\psi_i^{\langle 2\rangle}}{\partial a_i^{\langle 2\rangle}} = -\frac{S^{\langle 1\rangle} - \sum K_i a_i^{\langle 1\rangle} + \Delta}{(\sum K_i a_i^{\langle 2\rangle})^2}K_i$$

$$= -\frac{\psi_i^{\langle 2\rangle}}{\sum K_i a_i^{\langle 2\rangle}}K_i$$

(5) and (6) generate following two reaction equations:

$$\psi_i^{\langle 2\rangle} - \frac{K_i a_i^{\langle 2\rangle}}{(\sum K_i a_i^{\langle 2\rangle})^2}S^{\langle 2\rangle} = 0$$

$$\psi_j^{\langle 2\rangle} - \frac{K_j a_j^{\langle 2\rangle}}{(\sum K_i a_i^{\langle 2\rangle})^2}S^{\langle 2\rangle} = 0$$

$\psi_i^{\langle 2\rangle} = \psi_j^{\langle 2\rangle}$; $\frac{K_i}{(\sum K_i a_i^{\langle 2\rangle})^2}S^{\langle 2\rangle}$ in the second part of the reaction equation shows the slope of reaction curves. Since $\frac{S^{\langle 2\rangle}}{(\sum K_i a_i^{\langle 2\rangle})^2}$ is the common part in both the equations, slope of reaction curves vary according to the size of the cattle property K_i (K_j).

Solving them we get : $K_i a_i^{\langle 2\rangle} = K_j a_j^{\langle 2\rangle}$ .....(7)

Since the strategy of the game is backward induction the above sub-game perfect equilibrium solution will be rolled back into the stage 1 game. The game is solved by:

$$\frac{\partial}{\partial a_i^{\langle 1\rangle}}[K_i a_i^{\langle 1\rangle}\psi_i^{\langle 1\rangle}(\frac{S^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}})]+\frac{\partial}{\partial a_i^{\langle 1\rangle}}[K_i a_i^{\langle 2\rangle}\psi_i^{\langle 2\rangle}(\frac{S^{\langle 2\rangle}}{\sum K_i a_i^{\langle 2\rangle}})]=0$$

Plugging the value from (7) into the above equation, i.e $\sum K_i a_i^{\langle 2\rangle}=2K_i a_i^{\langle 2\rangle}$, considering $\psi_i^{\langle t\rangle}=\frac{S^{\langle t\rangle}}{\sum K_i a_i^{\langle t\rangle}}$, we get: $\frac{\partial}{\partial a_i^{\langle 1\rangle}}[K_i a_i^{\langle 1\rangle}(\frac{S^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}})]+\frac{\partial}{\partial a_i^{\langle 1\rangle}}[\psi_i^{\langle 2\rangle}.\frac{S^{\langle 2\rangle}}{2}]=0$ The first part of the equation is:

$$\frac{\partial}{\partial a_i^{\langle 1\rangle}}[K_i a_i^{\langle 1\rangle}(\frac{S^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}})]= K_i\frac{S^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}}-K_i{}^2 a_i{}^{\langle 1\rangle}\frac{S^{\langle 1\rangle}}{(\sum K_i a_i^{\langle 1\rangle})^2}=$$

$$K_i\frac{S^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}}-K_i{}^2 a_i{}^{\langle 1\rangle}\frac{\psi_i{}^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}} \quad .....(8)$$

The second part of the equation is:

$$\frac{\partial}{\partial a_i^{\langle 1\rangle}}[\psi_i^{\langle 2\rangle}.\frac{S^{\langle 2\rangle}}{2}]=\frac{1}{2}[S^{\langle 2\rangle}\frac{\partial\psi_i^{\langle 2\rangle}}{\partial a_i^{\langle 2\rangle}}\frac{\partial a_i^{\langle 2\rangle}}{\partial a_i^{\langle 1\rangle}}.+\psi_i^{\langle 2\rangle}\frac{\partial S^{\langle 2\rangle}}{\partial a_i^{\langle 1\rangle}}]$$

$$S^{\langle 2\rangle}=S^{\langle 1\rangle}+\Delta-\sum K_i a_i^{\langle 1\rangle}$$

$$\frac{\partial S^{\langle 2\rangle}}{\partial a_i^{\langle 1\rangle}}=-K_i$$

$$=-\frac{1}{2}K_i\psi_i^{\langle 2\rangle}[1+\frac{S^{\langle 2\rangle}}{\sum K_i a_i^{\langle 2\rangle}}\frac{\partial a_i^{\langle 2\rangle}}{\partial a_i^{\langle 1\rangle}}]$$

$$=-\frac{1}{2}K_i\psi_i^{\langle 2\rangle}[1+\psi_i^{\langle 2\rangle}\frac{\partial a_i^{\langle 2\rangle}}{\partial a_i^{\langle 1\rangle}}] \quad ....(9)$$

Combining (8) and (9) we get:

$$\frac{S^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}}-K_i\ a_i{}^{\langle 1\rangle}\frac{\psi_i{}^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}}-\frac{1}{2}\psi_i^{\langle 2\rangle}[1+\psi_i^{\langle 2\rangle}\frac{\partial a_i^{\langle 2\rangle}}{\partial a_i^{\langle 1\rangle}}]=0$$

Or, $\psi_i{}^{\langle 1\rangle}-K_i\ a_i{}^{\langle 1\rangle}\frac{\psi_i{}^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}}-\frac{1}{2}\psi_i^{\langle 2\rangle}[1+\psi_i^{\langle 2\rangle}\frac{\partial a_i^{\langle 2\rangle}}{\partial a_i^{\langle 1\rangle}}]=0$

Or, $\frac{K_i\ a_i{}^{\langle 1\rangle}}{\sum K_i a_i^{\langle 1\rangle}}=\frac{\psi_i{}^{\langle 1\rangle}-\frac{1}{2}\psi_i{}^{\langle 2\rangle}(1+\psi_i{}^{\langle 2\rangle}\frac{\partial a_i^{\langle 2\rangle}}{\partial a_i^{\langle 1\rangle}})}{\psi_i^{\langle 1\rangle}}$

Similarly for the *j*th player:

$$\frac{K_j \ a_j^{\langle 1\rangle}}{\sum K_j a_j^{\langle 1\rangle}} = \frac{\psi_j^{\langle 1\rangle} - \frac{1}{2}\psi_j^{\langle 2\rangle}(1+\psi_j^{\langle 2\rangle} \frac{\partial a_j^{\langle 2\rangle}}{\partial a_j^{\langle 1\rangle}})}{\psi_i^{\langle 1\rangle}}$$

$$\frac{\psi_i^{\langle 1\rangle} - \frac{1}{2}\psi_i^{\langle 2\rangle}(1+\psi_i^{\langle 2\rangle} \frac{\partial a_i^{\langle 2\rangle}}{\partial a_i^{\langle 1\rangle}})}{\psi_i^{\langle 1\rangle}} \sum K_i a_i^{\langle 1\rangle}$$

Proof of corollary 1

From (6.1) we get,

$$\psi_i^{\langle 2\rangle} + a_i^{\langle 2\rangle} \frac{\partial \psi_i^{\langle 2\rangle}}{\partial a_i^{\langle 2\rangle}} = 0;$$

Or, $a_i^{\langle 2\rangle} = \dfrac{-\psi_i^{\langle 2\rangle}}{\dfrac{\partial \psi_i^{\langle 2\rangle}}{\partial a_i^{\langle 2\rangle}}} = \dfrac{-\psi_i^{\langle 2\rangle}}{\dfrac{-\psi_i^{\langle 2\rangle}}{\sum K_i a_i^{\langle 2\rangle}} K_i} = \dfrac{\sum K_i a_i^{\langle 2\rangle}}{K_i}$, which decreases with K_i

References

Baland, J. M and Platteau, J. P., (1996) Halting degradation of natural resources: Is there a role for rural communities? Oxford: Oxford University Press.

Bardhan, P.K., and Dayton-Johnson, J (2002) Inequality and the governance of water resources in Mexico and South India in Maler, K.G and P Dasgupta (Ed)Handbook of Environmental Economics

Bardhan, P.K., Baland, J.M., Das, S., Mukherjee, D., and Sarkar, R.,(2001) Household firewood collection in Nepal

Bardhan, P.K., and Dayton-Johnson, J (2001) Unequal irrigators: Heterogeneity and commons Management in large-scale multivariate research, *Working paper*, Institute of International Studies, UC. Berkeley

Burton, P., (1993) Intertemporal preferences and intergenerational equity considerations in optimal resources harvesting, *Journal of Environmental Economics and Management 24, 119-132*

Chopra, K, Kadekodi, G.K. and Murty, M.N (1990) *Participatory development people and common property resources*, Sage Publications, New Delhi

Dasgupta, M., (1987) Informal security mechanism and population retention in rural India *Economic Development and Cultural Change, 36(1), 101-120*

Dasgupta, S and Mitra, T., (1983) Intergenerational equity and efficient allocation of exhaustible resources, *International Economic Review 24, 133-153}*

Dayton-Johnson, J and Bardhan (2002) Inequality and conservation on the local commons: A theoretical exercise, *Economic Journal, 112, 576-601*

Hackett, S, Dudley, D and Walker, J (1995) Heterogeneities, information and conflict resolution: experimental evidence on sharing contracts in Keohane, R. O and Ostrom, E (ed) *Local commons and global interdependence: heterogeneity and cooperation in two domains*, Sage Publications, New Delhi.

Hartwick, J. (1978) Substitution among exhaustible resources and intergenerational equity *Review of Economic Studies, 45, 347-354*

Heal and Dasgupta (1979) *Economic Theory and Exhaustible Resources*, Cambridge University Press, Cambridge

Jodha, N.S., (1986) Common property resources and rural poor in dry regions of India, *Economic and Political Weekly, 21(27), 1169-82*

Jodha, N.S., (1990) Rural common property resources: contributions and crisis *Foundation Day Lecture*, Society for promotion of wasteland development, New Delhi

Jodha, N.S.,(1992) Rural common property resources: the missing dimension of development strategies, *World Bank Discussion Paper 169,* The World Bank, Washington D.C

Johnson, R, N., and Libecap, G. D., (1982) Contracting problems and regulation: the case of the fishery, *American Economic Review, 72(5), 1005-22*

Jorgensen, S and Yeung, D., (2000) Intergenerational cooperative solution of a renewable resource extraction game, in Petrosjan, L.A., and Mazalov, V.V, (ed) *Game Theory and Applications VI*

McKloskey, D. N., (1976) English open fields as behaviour toward risk in Uselding, P. (ed) *Research in Economic History, Volume1*, Greenwich, Conn.

Olson, M., (1965), *The Logic of Collective Action,* Harvard University Press, Cambridge, Massachusets

Ostrom, E., (1996) Self-governance and forest resources, Occasional paper, 20, Center for International Forestry Research, Jakarta, Indonesia

Ostrom, E (1990) Governing the Commons: The evolutions of institutions for collective action, Cambridge University Press, Cambridge, Mass.

Rawls, J., (1971) A Theory of Justice, Cambridge, Harvard University Press

Solow, R. M., (1974) Intergenerational equity and exhaustible resources, Review of Economic Studies Symposium, 29-46

Stiglitz, J.E., (1974) Growth with exhaustible natural resources: efficient and optimal growth paths, *Review of Economic Studies, Symposium on the Economics of exhaustible resources, 41, 123-137*