A General Equilibrium Approach To Common Property Resource Exploitation

Sudhanshu Sekhar Rath, Uma Charan Pati

Abstract: From the normative point of view general equilibrium approach to the exploitation of common property resource is considered as the rule but in practice it is a myth in terms of Nash behavior, Non-Nash behavior and the Consistent Conjectural Equilibrium indicating the relevance of "Index of Tragedy". The elasticity of conjectured response examines the convergence of Non-Nash and Nash behavior for increasing group-size and at the other extreme explores the possibility of Pareto optimal behavior regardless of group size when its value rests on minus one. Consistent Conjecture Equilibrium generates a more pessimistic prediction for a group exploitation of the common property resource.

Index Terms: Common property resource, Group size, Nash behavior, Non-Nash behavior, Pareto equilibrium, Consistent Conjectural Equilibrium, Elasticity of Conjectured response, Index of Tragedy.
JEL Classification Code:D58, D62, Q20

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1. INTRODUCTION:

Common property resource has the mixed characteristics of both pure public goods and private goods. In the framework of a consumer- producer group, it possesses characteristics such as non-excludability and realness in consumption. This leads to the problem "Tragedy of Commons" as discussed by Hardin (1968). Property right means ownership right, user-right and tradable right on any property for which an individual or household is entitled. In the case of private property when the property right is clearly defined on the above points without any confusion, in a world of perfect information and costless transaction, prior entitlement of property right does not matter from an efficiency perspective and induce the property owner (if he is the negative externality creator through his activity) and the effected party to negotiate resulting in the Pareto optimality as illustrated by Coase (1960). The case of the common property is different. It only gives user right to any member of the group without the exclusive ownership right and the tradable right. This creates confusion, as the use of the resource is subtractive in the sense that use of it by any member would reduce the shares of the other members of the group. The objective of this paper is to theoretically analyze the exploitation of any common property resource of members in a group in terms of zero conjectural variation and non-zero conjectural variation examining the Nash and Non-Nash behavior respectively and to capture the "index of tragedy" in a general equilibrium perspective incorporating the group size. Section I contrasts Pareto optimality with Nash behavior. Hybrid or Non-Nash behavior is examined in between Nash equilibrium and Pareto optimal points in Section II. Section III captures the "Index of Tragedy" through a comparative analysis of Nash, Non-Nash and Consistent Conjectural Variation taking Pareto Equilibrium as the base.

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2. NASH BEHAVIOR AND PARETO OPTIMALITY:

Let all members of a community have the right to fish in a lake, which is considered as the common-property.

$$\text{Let } q = f(L) = f\left(\sum_{i=1}^{n} L_i\right) \qquad \text{(i)}$$

where q is the total catch (output of fish from the lake), L_i is the time spent fishing by the ith individual and $L = \sum_{l=1}^{n} L_i$, is the total time spent fishing by all n members of the group.

$$\therefore q_i = \frac{L_i}{L}.f(L) \qquad \text{(ii)}$$

L= $L_i + \bar{L}$, where $\bar{L} = \sum_{i=1}^{n} L_i \, i \neq j$

The net group benefit (Profit) from fishing in the lake is:

Π =Pq-WL (iii)

P and W are the prices of fish and time spent by the individual respectively.

Π is maximized when $\frac{\partial \pi}{\partial L} = \frac{\partial}{\partial L}(pq - WL) = 0)$

=> $\frac{\partial}{\partial L}[Pf(L) - WL] = 0$

=> P $f'(L) - W = 0$ (iv)

The optimal value of L, $\overset{*}{L}$, is uniquely determined by the first order condition, P $f'(L) = W$, being independent of the distribution of time spent fishing between individuals.

The solution is illustrated in Figure 1, where iso-profit contours $\pi_1\pi_1,\ \pi_2\pi_2,$ show the combination of $\left(L_i \text{ and } \bar{L}\right)$ corresponding to a constant profit level of the ithindividual

EE, depicts the Pareto optimal points showing all combinations L_i and $\bar{L}$ whose sum is L^*.

The Nash equilibrium corresponds to those L_i^* where the ith individual maximizes its profits while treating $\bar{L}$ as given. The individual's problem then is to

$$\text{Max} \left[Pf\left(L_i, \bar{L}\right) - WL_i\right] \qquad \text{(v)}$$

This is accomplished by time spent in fishing up to the point at which

$$Pf_{L_i}\left(L_i, \bar{L}\right) = W \qquad \text{(vi}$$

Iso-profit curve for the ith individual is expressed by the equation

$$\pi = Pf\left(L_i, \bar{L}\right) - WL_i$$

=>

$$d\pi = \frac{\partial}{\partial L_i}\left[Pf\left(L_i \bar{L}\right) - WL_i\right]dL_i + \frac{\partial}{\partial \bar{L}}\left[Pf\left(L_i, \bar{L}\right) - WL_i\right]d\bar{L} = 0$$

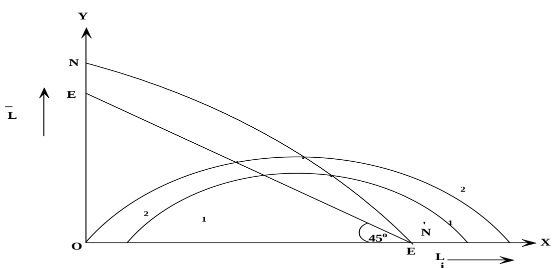

Figure 1 : Nash and Pareto Equilibria

=>

$$\left(Pf_{L_i} - W\right)dL_i + Pf_{\bar{L}_i}\, d\bar{L} = 0$$

=>

$$\left(Pf_{L_i} - W\right)dL_i = Pf_{\bar{L}}\, d\bar{L}$$

=>

$$\frac{d\bar{L}}{dL_i} = -\left(\frac{Pf_{L_i} - W}{Pf_{\bar{L}}}\right) = \frac{W - Pf_{L_i}}{Pf_{\bar{L}}} \qquad \text{(vii)}$$

At the maximum point of a iso-profit curve for the ith individual

$$\frac{d\bar{L}}{dL_i} = \frac{W - Pf_{L_i}}{Pf_{\bar{L}}} = 0$$

$$\Rightarrow W - Pf_{L_i} = 0, \text{or}, W = Pf_{L_i}$$

i.e. where the ith individual maximizes its profit treating $\bar{L}$ as given, i.e. the Nash behavior.

According to equation (vi)

$$Pf_{L_i}\left(L_i, \bar{L}\right) - W = 0$$

=>

$$\frac{\partial}{\partial L_i}\left[Pf_{L_i}\left(L_i, \bar{L}\right) - W\right]dL_i + \frac{\partial}{\partial \bar{L}}\left[Pf_{L_i}\left(L_i \bar{L}\right) - W\right]d\bar{L} = 0$$

=>

$$Pf_{L_iL_i}dL_i + Pf_{L_i\bar{L}}\, d\bar{L} = 0$$

=>

$$\frac{d\bar{L}}{dL_i} = \frac{-f_{L_iL_i}}{f_{L_i\bar{L}}} \qquad \text{(viii)}$$

gives the slope of the Nash reaction path.

Furthermore, when $\bar{L} = 0$, Nash behaviour implies the same level of L_i as does group profit maximization

Thus point E^1 and N^1 correspond to one another on the horizontal axis in Figure1. If the ith individual's production function is

$$f\left(L_i, L\right) = q_i = \frac{L_i}{L}.f(L) \qquad \text{(ii)}$$

=>

$$\frac{\partial q_i}{\partial L_i} = \frac{\partial}{\partial L_i} f\left(L_i, L\right) = f_{L_i}$$

$$= \frac{\partial}{\partial L_i}\left\{\frac{L_i}{L}.f(L)\right\}$$

$$= \frac{\partial}{\partial L_i}\left\{\frac{L_i}{\left(L_i + \bar{L}\right)}.f(L)\right\}$$

$$= \frac{\left(L_i + \bar{L}\right) - L_i.\frac{\partial \bar{L}}{\partial L_i}}{\left(L_i + \bar{L}\right)^2}.f(L) + f^1(L).\frac{L_i}{L_i + \bar{L}}$$

$$= \frac{\left(L_i + \bar{L}\right) - L_i}{L^2}.f(L) + f^1(L)\frac{\left(L - \bar{L}\right)}{L}$$

$$= \frac{\bar{L}}{L^2} f(L) + f^1(L) \frac{L - \bar{L}}{L}$$

$$= \frac{\bar{L} f(L)}{L^2} + f^1(L) - f^1(L) . \frac{\bar{L}}{L}$$

$$= f^1(L) + \frac{\bar{L}}{L}\left[\frac{f(L)}{L} - f^1(L)\right] \quad \text{(ix)}$$

$$\therefore f_{L_i \bar{L}} = \frac{\partial}{\partial \bar{L}}\left(f_{L_i}\right) = \frac{\partial}{\partial \bar{L}} f^1(L) + \left[\frac{\frac{f(L)}{L} - f^1(L)}{L}\right]$$

$$= f_{L_i L_i} + \frac{\left[\frac{f(L)}{L} - f'(L)\right]}{L} \quad \text{(x)}$$

$$=> f_{L_i \bar{L}} > f_{L_i L_i} \quad \text{(xi)}$$

$$=> f_{L_i \bar{L}} \big/ f_{L_i L_i} > 1$$

$$=> -\left(f_{L_i \bar{L}} \big/ f_{L_i L_i}\right) < -1$$

(Slope of the Nash reaction path), refer equation (viii)

$\therefore L_i + \bar{L} = \overset{*}{L}$ on the group profit maximizing locus ($E \overset{1}{E}$)

$$=> d L_i + d\bar{L} = 0$$

$$=> \frac{d\bar{L}}{dL_i} = -1 \quad \text{(xii)}$$

(Slope of group profit maximizing locus)

The slope of the Nash reaction curve is greater in absolute term than that of the group profit maximizing locus ($E \overset{1}{E}$).

3. NON-NASH BEHAVIOR:

Non-Nash behavior in the common property resource exploitation model is characterized by non-zero conjectural variation i.e. maximizing behavior that the ith exploiter holds in respect to the way in which the other exploiters will respond to his own fishing efforts. A general formulation for the non-zero conjectural variation is

$$\frac{d\bar{L}^e}{dL_i} = g(Q, L_i) \quad \text{(xiii)}$$

Where Q is a parameter (or vector of parameters), representing the other exploiter's time spent for fishing. Generally, (xiii) can be integrated to give an endogenous relationship for $\bar{L}^e$:

$$\bar{L}^e = \bar{L}^e(Q, L_i, K)$$

……………………………………………………………………… ………. (xiv)

where K is a constant of integration, depending on the rest of the fishing individuals' initial time spent for fishing.

The ith individual now chooses L_i, Such that

$$\pi_i^e = Pf\left[L_i, \bar{L}^e(Q, L_i, K)\right] - WL_i$$

is maximized.

$$\therefore d\pi_i^e = \left(P f_{L_i} - W\right) d L_i + P f_{\bar{L}^e} . d\bar{L}^e$$

$$=> \frac{d\pi_i^e}{dL_i} = P f_{L_i} - W + P f_{\bar{L}^e} . \frac{d\bar{L}^e}{dL_i} = 0,$$

for maximization of π_i^e.

$$=> P f_{L_i} + P f_{\bar{L}^e} . \frac{d\bar{L}^e}{dL_i} = W \quad \text{(xv)}$$

which degenerates to the Nash solution only when conjectural variations $\frac{d\bar{L}^e}{dL_i} = 0$. When, however $\frac{d\bar{L}^e}{dL_i} > 0,$ (implying that one's own increasing fishing effort is expected to induce others to follow suit), ith individual's optimal time spent for fishing and the common's tragedy will be less than that implied by the Nash solution since $W - P f_{L_i} > 0$ in equation (xv), which gives the Non-Nash solution. For negative conjecture, ith individual's optimal time spent on fishing exceeds those of Nash solution; the tragedy of the commons is intensified.

In Figure 2, three iso-profit curves are shown. Curves $K_1 \bar{L}^e, K_2 \bar{L}^e, \text{and } K_3 \bar{L}^e$ represent three endogenous paths for $\bar{L}^e$, each of which differs by the initial time spent on fishing by the rest of the members in the group.

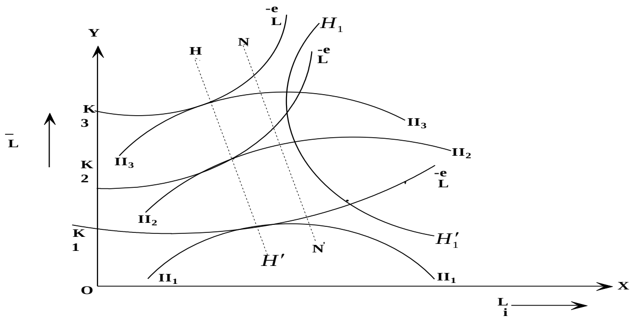

Figure:2 Hybrid Reaction Path

The slopes of these contours, $\frac{d\bar{L}^{e}}{dL_i}$, are the conjectural variations given in (xiii). The locus of tangencies between the iso-profit curves and the expectations contours trace out a hybrid reaction path, HH^1, for the ith individual. The path $H_iH_i^i$, is the hybrid path when conjectures are negative, the ith individual expects other to decrease their time spent on fishing in response to its increasing time spent for the purpose.

From equation (xv)

$$Pf_{L_i} + Pf_{\bar{L}^e}\frac{d\bar{L}^{e}}{dL_i} = W$$

$$\Rightarrow W - Pf_{\bar{L}_i} = Pf_{\bar{L}^e}.\frac{d\bar{L}^{e}}{dL_i}$$

$$\Rightarrow \frac{W - Pf_{\bar{L}_i}}{Pf_{\bar{L}^e}} = \frac{d\bar{L}^{e}}{dL_i} \qquad \text{(xvi)}$$

where the two sides of the equation corresponds to the slope of the iso profit curve and expectation contour, respectively.An interesting variety of behaviours can be displayed with the following specific formulation of the conjectural variation:

$$\frac{d\bar{L}^{e}}{dL_i} = \left(\frac{L_i}{\bar{L}}\right)^{\varphi} \qquad \text{(xvii)}$$

$$\Rightarrow Ln\left(\frac{d\bar{L}^{e}}{dL_i}\right) = \varphi Ln\left(\frac{L_i}{\bar{L}}\right)$$

$$\Rightarrow \frac{d\,Ln\left(\frac{d\bar{L}^{e}}{dL_i}\right)}{dLn\left(L_i/L\right)} = \varphi \text{ i.e.}$$

the elasticity of the conjectured response with respect to the relative time spent by the ith individual as a proportion of total time spent by the group for fishing.

When there are n identical individuals in the group

$$n.L_i = L \qquad \text{(xviii)}$$

$$\Rightarrow n.L_i = \bar{L} + L_i$$

$$\Rightarrow (n-1)L_i = \bar{L}$$

$$\Rightarrow \frac{L_i}{\bar{L}} = \frac{1}{(n-1)} = (n-1)^{-1} \qquad \text{(xix)}$$

Substituting equation (xix) in (xvii)

$$\frac{dL^{-e}}{dL_i} = (n-1)^{-\varphi} \qquad \text{(xx)}$$

$$\Rightarrow \frac{W - Pf_{L_i}}{Pf_{\bar{L}^e}} = (n-1)^{-\varphi} \qquad \text{(xxi)}$$

refer equation (xvi).

Figure 3 illustrates the specific formulation for three different values of φ. Equilibrium can be found as the number of individuals varies by focusing on tangencies (for Pareto points) and maxima (for Nash points) along different rays from the origin. For example, a ray with a slope of 1 corresponds to n-2, since $\frac{\bar{L}}{L_i} = 1$, a ray with a slope of 2 relates to n=3, since $\frac{\bar{L}}{L_i} = 2$, and son on.

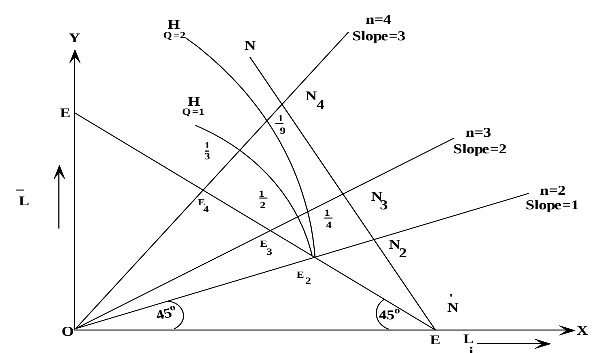

Figure 3 : Identical Individuals

$$\frac{d\bar{L}^{e}}{dL_i} = (n-1)^{-\varphi}$$

Hybrid (Non-Nash) equilibrium can also be found along these rays. When

$\varphi \geq 1$, the dashed paths in Figure 3 are the hybrid paths. Points along it satisfy

$$\frac{W - P f_{L_i}}{P f_{\frac{-e}{L}}} = (n-1)^{-\varphi}$$

(xxi),

hence refers to tangencies between the expectation contours and the iso-profit curves. The hybrid equilibrium for n-3, when φ=1 for example, corresponds to the lowest iso-profit curve with slope 1/2 on the ray with slope 2. The hybrid path for n=3, when φ=2, corresponds to iso-profit curve with slope $1/4$ on the ray with slope 2. It displays a faster convergence to Nash-behaviour as group size grows than that associated with φ=1. This formulation contains the following implications:

Values of $\varphi \geq 1$ imply a convergence to Nash behaviour as group size grows.

The larger the φ (provided that $\varphi \geq 1$) the faster is this convergence.

φ= -1, indicates Pareto optimal behaviour regardless of group size.

4. INDEX OF TRAGEDY:

In Figure 3 Pareto optimal points for different group size lie along EE^1, whereas Nash equilibriums are on NN^1. Subscripts indicate group size. The ratio $\frac{ON_i}{OE_i}$ expresses an "index of tragedy". Ratios greater than 1 correspond to a misallocation, where large ratios imply greater inefficiency.

From the analysis of section III, it is derived from the figure 3 that Non-Nash equilibrium converges to Nash equilibrium for all values of $\varphi \geq 1$ hence from the point of view of the Non-Nash behaviour also "Index of tragedy" is relevant exhibiting direct relationship between group size and "Index of tragedy". In addition to this for $\varphi \geq 1$, there is the tendency for higher value of the "Index of tragedy" even for the same group size for the increasing value of φ. However, φ=-1, completely avoid the possibility of "Index of tragedy", regardless of the group size as it indicates Pareto Optimal behaviour. In the context of the comparison between Nash and Non-Nash behaviour concentrating on "Index of tragedy" positive conjectural variation establishes superiority of Non-Nash equilibrium to those of Nash as NN^1, lies to the right of HH^1.

If the conjectural variation is negative NN^1 moves to the left of $H_1H_1^1$ giving the opposite result, refer figure 2.

Suppose variations in total fish output from the lake have no effect on the price of fish P and similarly that variation in total time spent for fishing (total labour input to fishing) in the lake have no effect on the wage rate W.

$$\therefore \pi_i = Pq_i - WL_i \qquad (1)$$

To maximize π_i w.r.t L_i

$$\frac{d\pi_i}{dL} = \frac{d}{dL_i}\left(Pq_i - WL_i\right)$$

$$= \frac{d}{dL_i}\left(P.\frac{L_i}{L}f(L) - WL_i\right) = 0 \qquad (2)$$

$$=> \frac{d}{dL_i}\left(P.\frac{L_i}{L}f(L)\right) - W = 0$$

$$=> P.\frac{d}{dL_i}\left[L_i\left(\frac{f(L)}{L}\right)\right] - W = 0$$

$$=> P\left[\left(\frac{d}{dL_i}L_i\right)\frac{f(L)}{L} + L_i\frac{d}{dL_i}\left(\frac{f(L)}{L}\right)\right] - W = 0$$

$$=> P\left[\frac{f(L)}{L} + L_i\left(\frac{f^1(L).L - f(L)}{L^2}\right)\right] - W = 0$$

$$=> P\left[\frac{f(L)}{L} + \frac{L_i}{L}\left(f^1(L) - \frac{f(L)}{L}\right)\right] - W = 0$$

$$=> P\left[\frac{f(L)}{L} + \frac{L_i}{L}\left(f' - \frac{q}{L}\right)\right] - W = 0 \qquad (3)$$

$$=> \frac{Pq}{L} - W = P.\frac{L_i}{L}\left(\frac{q}{L} - f^1\right) \qquad (4)$$

In equation (1) $\pi_i = Pq_i - WL_i$

$$= P.q.\left(\frac{L_i}{L}\right) - WL_i = \left(P\frac{q}{L} - W\right)L_i$$

$\pi_i > 0,$ for $L_i > 0$

$$=> P.\frac{q}{L} - W > 0$$

$$=> P.\frac{L_i}{L}\left(\frac{q}{L} - f^1\right) > 0$$

Substituting equation (4)

$$=> \frac{q}{L} - f^1 > 0$$

$$=> \frac{q}{L} > f^1$$

This implies $AP_L > MP_L$ so MP_L curve remains below AP_L curve, means MP_L is declining considering production of fish for the group as a whole. The profit for the group as a whole is maximized at $\overset{*}{L}$ where

$$\frac{d}{dL}\left[Pf(L)-WL\right]=0$$

=> $Pf^1 - W = 0$ (5)

The Pareto optimal outcome could be achieved if all the members with fishing right can agree to reduce their total labour to $\left(\sum_{i=1}^{n} L_i = \overset{*}{L}\right)$, refer to Pareto equilibrium in section II. The marginal profit from the extra L_i is (See equation (3))

$$P\left[\frac{f(L)}{L}+\frac{L_i}{L}\left(f^1-\frac{q}{L}\right)\right]-W$$

$$= P\left[\frac{q}{L}+\frac{L_i}{L}\left(f^i-\frac{q}{L}\right)\right]-W$$

………………………………………………(6)

at $\overset{*}{L}$, $Pf^i = W$
(refer equation,5)

Substituting W= Pf^i in equation (6),

$$\frac{d\pi_i}{dL_i}=P\left[\frac{q}{L}+\frac{L_i}{L}\left(f'-\frac{q}{L}\right)\right]-Pf'$$

$$=\left(P\frac{q}{L}-Pf'\right)+P\frac{L_i}{L}\left(f'-\frac{q}{L}\right)$$

$$=P\left[\left(\frac{q}{L}-f'\right)+\frac{L_i}{L}\left(f'-\frac{q}{L}\right)\right]$$

$$=P\left[\left(\frac{q}{L}-f\right)-\frac{L_i}{L}\left(\frac{q}{L}-f'\right)\right]$$

$$=P\left[\left(1-\frac{L_i}{L}\right)\left(\frac{q}{L}-f'\right)\right]$$

$$=P\left(\frac{q}{L}-f'\right)\left(1-\frac{L_i}{L}\right) \quad (7)$$

When $\frac{q}{L} > f^i$ for the group

$$\frac{d\pi_i}{dL_i} > 0$$

It implies when any individual member (ith member) treats $\frac{\partial q_i}{\partial L_i} = 0$, for profit maximization, at the Pareto Optimal point where $\overset{*}{L}$ hours for the group as a whole is spent for fishing, in reality $\frac{\partial q_i}{\partial L_i} > 0$, so there will always be an incentive for the individual member of the group to increase L_i. User right in the case of common property gives unrestricted access to members which lead in this example to overly intensive use. Finally the Pareto Optimal group exploitation of the common property resource gets violated in this process and the final equilibrium occurs at that point, which gives zero profits. In other words consistent conjectural equilibrium requires zero profits in the group highlighting over exploitation making the inbuilt "Index of tragedy" relevant for the group that constitutes more than a single member.

5. CONCLUSION:

Nash behaviour, Non-Nash behaviour, and the consistent conjectural equilibrium in the exploitation of common property resources prove the divergence from Pareto optimality, explaining the fact that general equilibrium approach to the exploitation of common property resource is considered as the rule from the normative point of view. This article explores the possibility of collective action in the group for the achievement of Pareto optimality in the utilization of common property resource getting facilitated through all identical members in the group in terms of their taste and endowment. The Nash equilibrium, while it suggests over exploitation of the resource, generates a less pessimistic prediction than does the consistent conjecture equilibrium in this latter context, even two members in a group are considered as large for the exploitation of common property resource as it leads to over exploitation. General equilibrium approach to common property resource exploitation depends on the effective management of common property resource through group formation and collective action.

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